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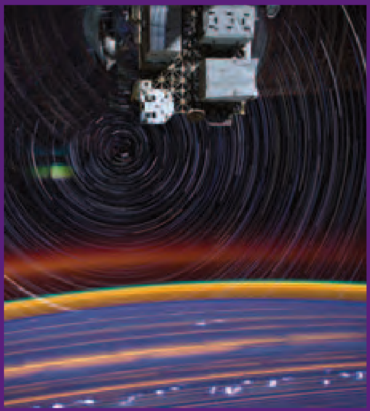

Photo Credit: NASA/Don Pettit

ON THE COVER

This is a composite of a series of images photographed from a mounted camera on the Earth-orbiting International Space Station, from approximately 240 miles above Earth. Expedition 31 Flight Engineer Don Pettit said of the photographic techniques used to achieve the images: “My star-trail images are made by taking a time exposure of about 10 to 15 minutes. However, with modern digital cameras, 30 seconds is about the longest exposure possible, due to electronic-detector noise effectively snowing out the image. To achieve the longer exposures I do what many amateur astronomers do. I take multiple 30-second exposures, then ‘stack’ them using imaging software, thus producing the longer exposure.” A total of 18 images photographed by the astronaut-monitored stationary camera were combined to create this composite.

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The Academy of Program/Project and Engineering Leadership (APPEL) and *ASK Magazine* help NASA managers and project teams accomplish today's missions and meet tomorrow's challenges by sponsoring knowledge-sharing events and publications, providing performance enhancement services and tools, supporting career development programs, and creating opportunities for project management and engineering collaboration with universities, professional associations, industry partners, and other government agencies.

ASK Magazine grew out of the Academy and its Knowledge Sharing Initiative, designed for program/project managers and engineers to share expertise and lessons learned with fellow practitioners across the Agency. Reflecting the Academy's responsibility for project management and engineering development and the challenges of NASA's new mission, *ASK* includes articles about meeting the technical and managerial demands of complex projects, as well as insights into organizational knowledge, learning, collaboration, performance measurement and evaluation, and scheduling. We at APPEL Knowledge Sharing believe that stories recounting the real-life experiences of practitioners communicate important practical wisdom and best practices that readers can apply to their own projects and environments. By telling their stories, NASA managers, scientists, and engineers share valuable experience-based knowledge and foster a community of reflective practitioners. The stories that appear in *ASK* are written by the "best of the best" project managers and engineers, primarily from NASA, but also from other government agencies, academia, and industry. Who better than a project manager or engineer to help a colleague address a critical issue on a project? Big projects, small projects—they're all here in *ASK*.

You can help *ASK* provide the stories you need and want by letting our editors know what you think about what you read here and by sharing your own stories. To submit stories or ask questions about editorial policy, contact Don Cohen, Managing Editor, doncohen@rcn.com, 781-860-5270.

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In This Issue

Everyone who is familiar with NASA missions knows that most of them involve collaboration among many organizations and individuals. Project teams often include several NASA centers, other countries' space agencies, industry partners, and universities. Review board members and other experts not officially part of project teams contribute their knowledge and advice. Very few missions could get off the ground—literally or figuratively—without a broad assembly of resources and expertise.

Several of the articles in this issue of *ASK* show that the work that makes many projects possible goes far beyond even those extensive collaborations. Behind every ambitious mission is a whole history of earlier projects that laid the groundwork for later accomplishments and helped develop the skills engineers, scientists, and managers need to carry out current and future work. NASA projects don't happen in isolation; they are part of a wide web of interrelated efforts.

Look, for instance, at "Building a Better Telescope: The Legacy of NASA's Balloon Missions." That article and the companion piece on producing mirrors for the Nuclear Spectroscopic Telescope Array (NuSTAR) show just how essential balloon-based X-ray telescope missions at several NASA centers have been to NuSTAR and other, planned orbital observatories. The balloon missions have been a training ground for graduate students who would become project scientists on future missions; the missions' early work on the technical challenge of designing and building X-ray telescopes made the NuSTAR instruments possible, and continuing technical work by the balloon teams will benefit future missions. Years of balloon work have built international communities of scientists and engineers whose shared expertise is being applied to sophisticated instruments like the Astronomical Roentgen Telescope scheduled for launch on a Russian-led orbital mission.

In "Earth's Bridge to Space," Stefano Coledan shows how today's successes are built on earlier work. Behind the Launch Services Program's ability to ensure the successful launch of current and future missions lies decades of experience and expertise.

IceBridge is another mission closely linked to past and future missions ("Collaborative Planning for IceBridge Science"). Using aircraft to gather data about polar ice, it is bridging the gap between past and future satellite missions; IceBridge scientists are shaping how they collect data to ensure consistency with the satellite scheduled for launch in 2016.

"Hard Lessons and Lean Engineering" discusses Morpheus and the Autonomous Landing Hazard Avoidance Technology, projects that are among the building blocks of what will eventually be technologies that make future asteroid and planetary landings possible. The article also deals with an important subject—doing good work on a tight budget—that is a fact of life throughout the agency and another theme of several articles.

Joyce Abbey's "The Transformation of MOD" is a case in point. It details the extensive and innovative steps Johnson Space Center's Mission Operations Directorate has been taking to make sure they can continue to provide the same quality of service at much-reduced cost. "Safety Day Collaboration" by Mike Lipka and David Miranda's "Spaceport Innovators" also provide examples of NASA employees finding ways to accomplish their aims with little or no money to spend. These articles show that creativity and collaboration are not limited to technological and scientific achievement; they also contribute to efficiency and good management and help NASA do a lot with a little.

Don Cohen
Managing Editor

From the NASA CKO

Living in Uncertainty

BY ED HOFFMAN

Project-based organizations like NASA have a paradox embedded in their DNA: the tension between the organization's need for stability and the inherent uncertainty of complex projects.

My colleague Terry Cooke-Davies, global chairman of Human Systems, captured this well a few weeks ago at our Engaging Leaders in Knowledge event:

> The way senior management thinks and the way a program manager thinks are completely different. If you are a business manager, you know how you plan. If you are a project manager, you know how you plan. The difference is, the same word means totally different things in the two different contexts.
>
> If you are a business manager, plans start by looking at what we did last year. The way we get to our plans for this year is we look at what we did last year and look how it needs to change for this year and into the future. So planning starts from a known reality and moves into a kind of unknown, hoped-for future.
>
> In projects, what you start with isn't a known reality; you start with a dream. You start with a wish, you start with a desire, you start with somebody's intention that you are going to end up with a new service or product or something delivered, but when you set out, you do not know for sure that it is doable. You don't have a known baseline. You have your best guess of what will need to be done to deliver it. That is a very different activity.

At first glance, it would seem that the best way to master this tension would be to routinize projects and make them more predictable. The problem is that the typical NASA project is a one-of-a-kind system. Innovation is a precondition of its success. This has been true of everything from Project Mercury's Big Joe to Mars Curiosity. Innovation often defies tidy schedules and budgets. In a recent article in *Wired*, Stephen Attenborough, the first employee of Virgin Galactic, described the challenge of soliciting passengers for the company's commercial spaceflight venture:

> We were saying, "Look: we don't know how long this project's going to last, we don't know when the product's going to be delivered; we don't know what it's going to look like; we don't really know much about what it's going to be like for you on board; we don't [know] whether you're going to be eligible to fly, because we don't understand too much about the fitness requirements … but if you want to join, we need $200,000 up front."

This is fundamentally similar to the challenge that many NASA projects face. We need resources in advance just to define the requirements of projects that begin with long lists of uncertainties. The quality necessary to survive in this environment is adaptability, which can be at odds with a larger organizational culture that values stability.

The best program and project managers understand that the key to handling this tension is communicating in the right key for different audiences. Senior management needs one level of reporting so they can show NASA's stakeholders that the agency is being a responsible steward of the taxpayer's dollars. Without that, no projects get funded. Team members, partners, and vendors need other kinds of detailed communication about day-to-day specifics. None of this removes the inherent uncertainty of complex projects, but it makes it easier to live with the paradox. ●

HARD LESSONS AND LEAN ENGINEERING

BY KERRY ELLIS

Morpheus ground-level hot fire on April 2, 2012, at Kennedy Space Center's Vertical Test Bed Flight Complex.

Photo Credit: NASA/Joe Bibby

Future human space exploration will mean getting beyond low-Earth orbit—and returning safely. Several projects across NASA are working on the challenges that goal presents, among them propulsion alternatives and guidance, navigation, and control. Three years ago, Project Morpheus and the Autonomous Landing and Hazard Avoidance Technology project, or ALHAT, began collaborating on advances in these areas.

ON THE ENGINEERING SIDE, THE PHILOSOPHY HAS FOCUSED ON A TEST EARLY, TEST OFTEN APPROACH USING LOW-COST MATERIALS THAT CAN BE FOUND COMMERCIALLY OR QUICKLY MODIFIED.

Morpheus is a rapid-prototype vertical lander concept testing many ideas at once. It is known as a vertical test bed: a lander that can be adjusted, scaled, and reconfigured to test different design ideas. This makes it a great platform on which to test ALHAT's sensors and software, meant to detect hazards in real time and adjust flight trajectories to avoid them without human intervention.

Together, they can provide a template for future planetary landers, one that can scale down for asteroid missions or potentially scale up for human spaceflight to Mars.

Lean Engineering

To provide quick technology demonstrations, both projects have focused on keeping their management and engineering approaches lean and mean. For the project managers, this has meant finding ways to document processes and lessons learned with enough rigor to satisfy requirements and benefit current and future projects but without a mountain of paperwork that might prevent rapid design and development. On the engineering side, the philosophy has focused on a test early, test often approach using low-cost materials that can be found commercially or quickly modified.

At the core of these approaches has been collaboration and communication. The Morpheus and ALHAT teams have looked to their peers at other centers to provide their expertise and knowledge to the projects, and to industry partners with experience in operating rapid-prototype projects.

According to Jon Olansen, Morpheus project manager, Morpheus is about 90 percent in-house collaboration spanning several NASA centers, including Johnson Space Center, Goddard Space Flight Center, Stennis Space Center, Kennedy Space Center, and Marshall Space Flight Center. "By keeping the work predominantly in house, our civil servants have learned a tremendous amount," he said. The team includes experienced personnel as well as those new to the agency and students. "We have all learned so much doing this hands-on work, and I think the benefit to the agency is astronomical. It's been a great training ground."

One lesson Morpheus has taken from its commercial partners is finding the right level of documentation. In one instance, the team worked closely with Armadillo Aerospace to see how a small development team operated. They learned how to improve processes for lean development and were able to pass on some NASA knowledge to improve Armadillo's safety and process measures.

"We decided to pick and choose from procedural requirement 7120.5 and the agency's project management policies to determine what was applicable to Morpheus. Those policies primarily exist for larger projects and programs, but they're a great information source for project management if appropriately tailored to your project," explained Olansen. "We don't produce a bunch of documents, and we only produce a handful for written signatures, such as range-safety documents." Everything else is kept online to ensure the project has enough rigor regarding safe operations and capturing lessons learned.

"Engineers like to do things, not write documents," added Chirold Epp, project manager for ALHAT, "so as a project manager, I have to work a bit to make sure we document what we've done, and people can pick it up and understand what we did right and what we did wrong. Our effort has been to document all data whenever we do a field test and ensure it's readable; otherwise, you can spend way too much time writing documents. We need to do the work. And for good technology development, we believe that's the right way to go."

The lean development approach also applies to the engineering itself, often relying on "good enough" solutions that will allow for safe testing and progressive learning in the moment.

On Morpheus, for example, engineers needed to figure out how propellant would slosh within their fuel tanks. Usually, this requires a lot of time creating and analyzing models before development takes place. Instead, one of the engineers went to a hardware store and spent $80 on wood, attachment fittings, four light globes, and food coloring. They put together a simple

Crash site after Morpheus's second free-flight attempt.

model of Morpheus's four-tank structure, filled the globes with colored water, hung it from a single point, and induced oscillations to see how the fluid would slosh within the globes.

"We could see that if we induced an oscillation in one direction, eventually the water would swirl in the globes instead of slosh back and forth, due to the tank configuration. It got us 80 percent of the answer," explained Olansen. "It didn't give us every detail, but it gave us plenty of information to design baffles we could put into the tanks to reduce slosh to the point where it's not an impact to the way we fly. It's great for a prototype, but it would require more work if we were going to fly in space with a follow-on vehicle. But we now have an 80-percent solution, and it cost us $80 to get it there."

"Because you don't always have the money to buy the most expensive and best parts, you've got to build something that works, then go out and test," added Epp. "You just proceed in that fashion and move ahead."

Both teams follow a build-test-build philosophy. "When you do that kind of testing, things don't always work how you expect. But you learn, then you go back and do it again," said Epp.

Crucial to that learning is good communication—across the team and up the chain of management. Since the combined teams include seven NASA centers and a few commercial partners spread out across the nation, much of the communication happens in teleconferences and e-mail, but Olansen and Epp are co-located at Johnson and get folks face to face when needed.

"Whenever we felt it was necessary to get the group together face to face, we would do that. You can do a lot with telecommunications, but sometimes you still need to get together and talk," said Epp. Early on, the ALHAT team got together four times a year for a few days to review what they were learning and how to proceed. "This year we moved everything initially to Langley Research Center and tested there with the whole team: Jet Propulsion Laboratory, Langley, Johnson, and Draper Laboratories. Then we came to Johnson and brought everyone here to work on Morpheus."

Crash Landing

After several successful tethered tests at Johnson—where the Morpheus lander was held aloft by crane and its thrusters fired for continuous periods—both teams were anticipating the first free-flight attempt. They began at Kennedy on August 3 with another tethered test to ensure all systems were working as expected. Everything checked out. No shipping-related issues were found.

On August 7, Morpheus made its first free-flight attempt. The vehicle successfully rose a couple feet off the ground but, shortly after liftoff, sensors onboard the vehicle falsely detected an engine burn-through. The rest of the system reacted as programmed: it initiated a soft abort, descended to the launchpad, and shut off its engines.

"The test lasted probably a total of 7 seconds," said Olansen. "We brought the vehicle back to the hangar, and we knew immediately it was a false indication, which we fixed." During that review, the team discovered the lander's footpads had melted slightly from being in the engine plume. They reached out to the thermal-protection experts at Kennedy for advice. "They came up with a design using excess shuttle materials, implemented it, and built new thermally protected footpads for us in about four hours."

Two days later, they were ready to try again. Loaded with mass simulators to represent the ALHAT payload—the actual sensors would be used once free-flight tests completed successfully—Morpheus again fired up its engines and began to ascend. Just 0.6 seconds after liftoff, the lander experienced data loss from its inertial measurement unit (IMU), the prime navigation sensor that tells the vehicle where it's headed.

"Without that data, the vehicle had no way to control itself," Olansen explained. "It continued to try to respond to the last piece of data it had, which was a slight correction in attitude. As a result, it continually corrected for that pitch error and never received information it was corrected, which resulted in a parabolic flight trajectory."

While Morpheus rebuilds, the Autonomous Landing Hazard Avoidance Technology team continues testing their sensors by attaching them to a helicopter and performing field tests.

Morpheus crashed—and the crash was streamed live on the Internet. The response, both within the agency and from external news media, was immediate. Calls and e-mails came pouring in. Those from the agency, including from Administrator Charles Bolden, were supportive and reassuring. Upper management let the team know immediately the project would continue, and they should work to recover, learn, and improve the next build.

For Olansen, the toughest part of being a manager during the time immediately following the crash was ensuring his attention wasn't pulled away from his team. Because everything was streamed publicly, there was a lot of attention that required his response. "Instead of responding to those things right away, the first thing I did was ensure the emergency procedures and recovery activities were occurring properly. Take care of the important things first and make sure the team, the hardware, and everything else was safe," he said.

As the team picked up the pieces from the crash site, Olansen paused to gather everyone in the middle of the field and let them know their efforts were not over; Morpheus wasn't canceled; this was a chance to learn and make the next lander better.

The failure investigation never escalated to a full, formal mishap investigation largely because the team's communication and documentation had been robust, even with its scaled-back customization.

The team worked to "pre-declare" expected test outcomes, a process introduced for rapid-prototype projects at NASA. Gerry Schumann, the mishap investigator program manager at Kennedy, sat down with the project managers and safety personnel to define the potential risks. "Tests are just that: tests," he said. "If we pre-declare what might go wrong through fault analysis and perform engineering analysis afterward, then we don't need a full-blown mishap investigation.

"Appropriately notifying everyone when the crash happened was also important," Schumann added. "Terry [Wilcutt, NASA's chief of safety and mission assurance] knew right away it was not a mishap because I notified him that this outcome was identified in a pre-declare."

"When Terry got the initial notification, his quick response was this does not rise to the threshold for NASA mishap," said Mike Ryschewitsch, NASA's chief engineer. "From his perspective and my perspective, they had pre-identified that loss of the hardware was one of the possible outcomes and had done a very thorough job of safety planning to protect against the worst-case incident, which was what actually did happen, to be sure that no one would get hurt. If either one of those had not been true … then it would have been a different slice."

Morpheus's deputy project manager, Stephen Munday, led the failure-investigation meetings that followed, sitting down with Olansen to discuss findings and next directions, which were communicated to the team, who were simultaneously working on design improvements. Since much of the evidence had burned in the crash, a definitive root cause could not be determined. But knowing the IMU failure contributed to the crash and analyzing the flight data they could recover, the team deduced that heavy vibration likely led to connectors from the IMU losing contact.

"We were able to recover vibration data all the way through the crash, and we could evaluate and assess the vibro-acoustic environment, which we believe was a significant player in the cause of the crash," said Olansen. "We know there was a failure between the IMU and the computer that was receiving the data, but the computer itself and the software were working fine. It was in the transmission from the IMU to the computer where the problem occurred. There are cable connectors, bus couplers, and the IMU itself—any of those components could have been the failure and would have provided the signature we saw."

To reduce the chance of recurrence, they are adding a second IMU and will isolate both units from vibration (which was not done initially because isolation could affect the vehicle's

Photo Credit: NASA/Joe Bibby

The team prepares Morpheus for attachment to the crane rigging.

Photo Credit: NASA/Kris Kehe

The witness plate is installed to gauge the environment during liftoff. Damage, if any, sustained during the firing is valuable data for future sensor positioning.

AS THE TEAM PICKED UP THE PIECES FROM THE CRASH SITE, OLANSEN PAUSED TO GATHER EVERYONE IN THE MIDDLE OF THE FIELD AND LET THEM KNOW THEIR EFFORTS WERE NOT OVER; MORPHEUS WASN'T CANCELED; THIS WAS A CHANCE TO LEARN AND MAKE THE NEXT LANDER BETTER.

ability to meet ALHAT's stringent pointing requirements). In addition, they plan to upgrade the cable connectors and bus couplers with military-grade hardware as well as create a flame trench on their launchpad to reduce the vibration.

Confident they will have a lander on which to test their payload, the ALHAT team has proceeded with testing and improvements to their sensors.

"We realized there was going to be a lull, so we quickly set out to run a helicopter test and fly trajectories toward the hazard field using our sensors exactly the way we would fly them on Morpheus," said Epp. "And that has turned out to be extremely valuable. It's going to help us get a big head start on success once Morpheus flies again. Our sensors are being updated and improved based on that helicopter test. And that test has gotten our team excited."

"We didn't stand the team down while we did a failure investigation," said Olansen. "A couple of us focused on the failure investigation, but the rest of the team focused on the redesign effort, the improvements we needed, and the rebuild. We still put rigor into the failure investigation, but we didn't have the whole team stand down to do that. I think giving them something to look forward to and work toward, which was driving them the couple years prior, was a key component to getting back on the horse."

Epp added, "The impact to us wasn't quite as bad as it was for Morpheus, but one of the things I always try to seize on is opportunity. Failure frequently opens up opportunity. Suddenly there was opportunity for us to make our system better. The whole idea of moving on and finding ways to do it better became a pretty good rallying point."

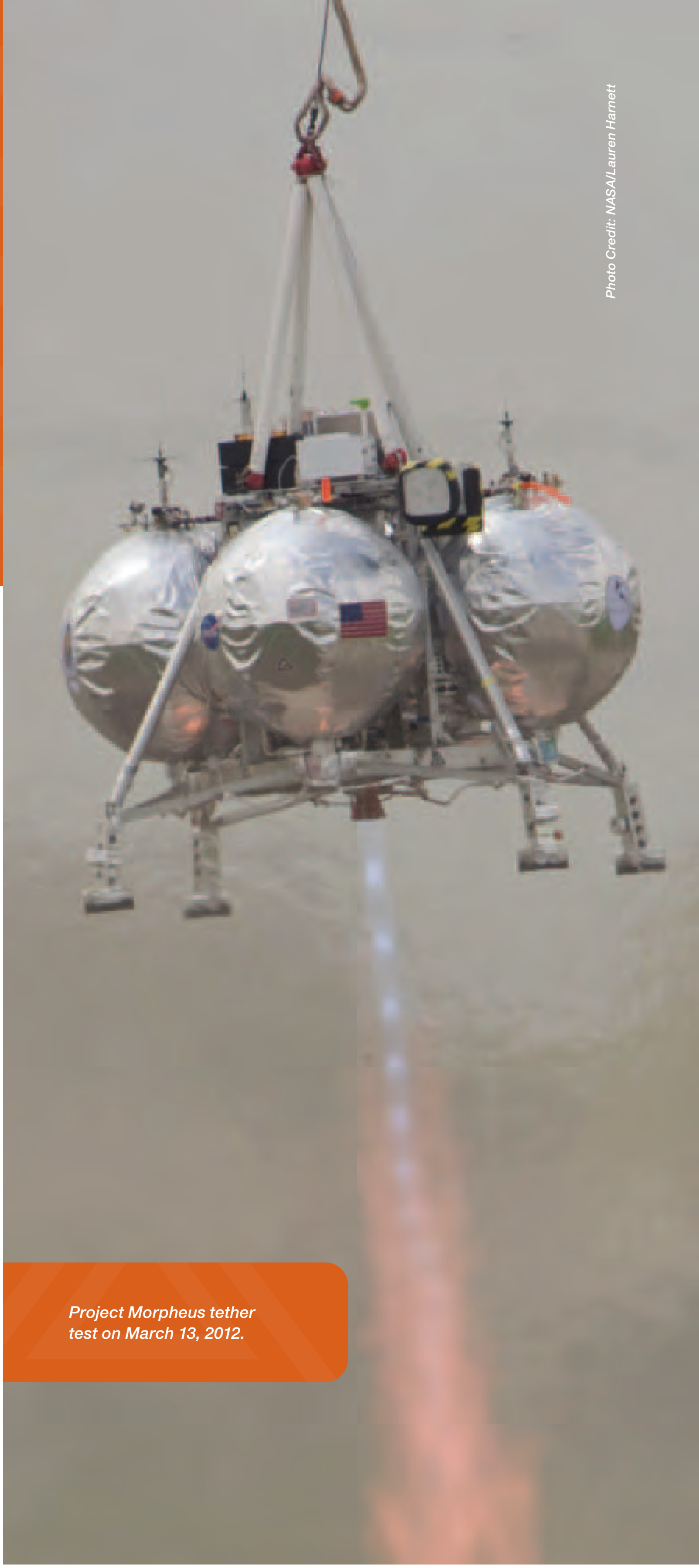


Photo Credit: NASA/Lauren Harnett

Project Morpheus tether test on March 13, 2012.

Future Flight

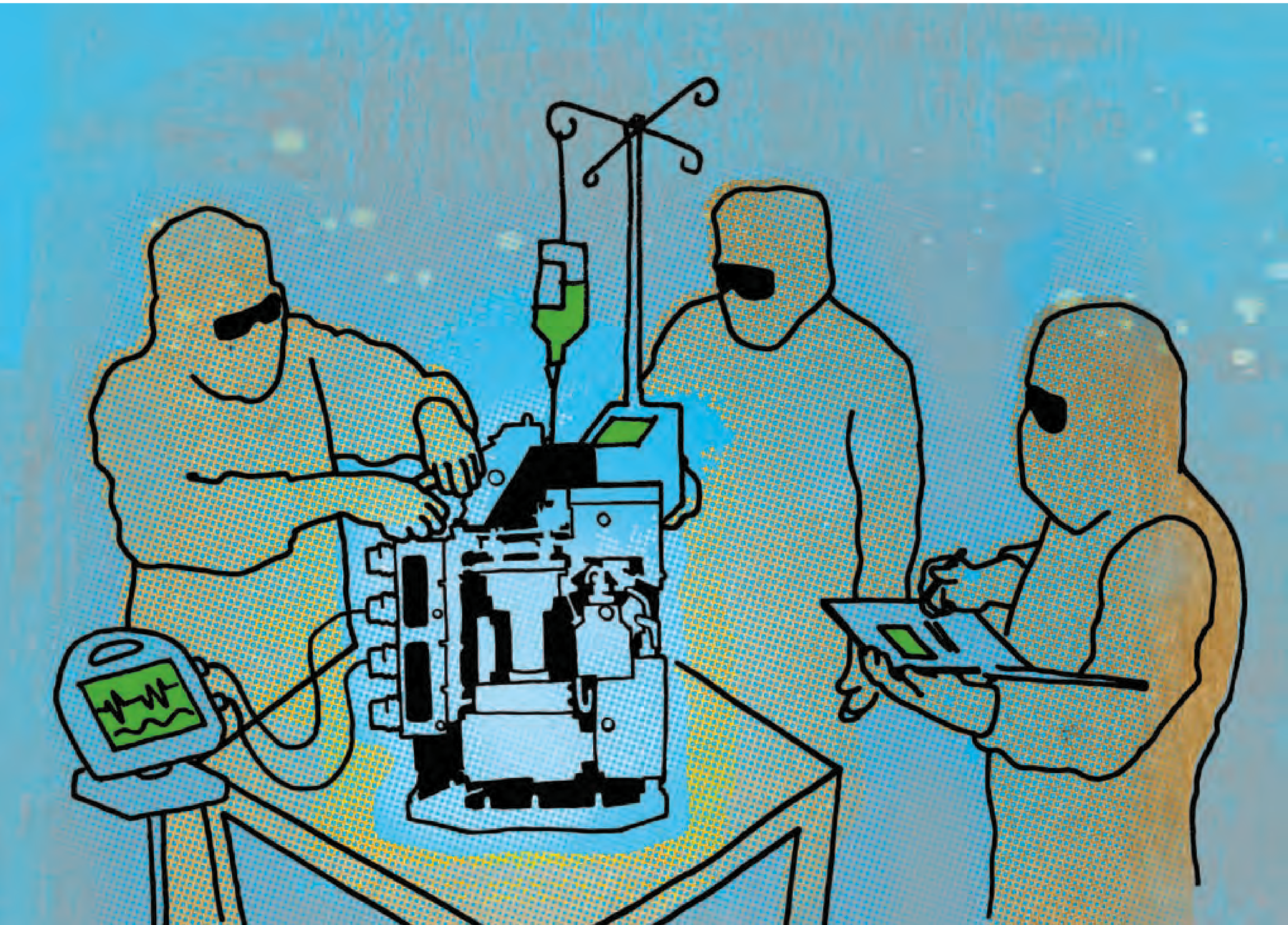
Since last summer, the Morpheus and ALHAT teams have become a single team, though not much has changed in the way they work together. The camaraderie and trust that existed before continue today.

"I've been with NASA for a while, and NASA culture rallies around accidents and failure," said Epp. "NASA has a culture that says pick your feet up, figure out what went wrong, and do it better. I've seen that over and over again, and I think this was another beautiful illustration of that."

The Challenge of Launching Old Scientific Instruments

BY KAREN HALTERMAN

Scientific instruments for robotic NASA space missions are usually designed for flight on a specific satellite with a planned launch date. Sometimes multiple copies of instruments are developed to fly on several satellites. Occasionally, the last instrument in the series is launched years after originally planned and may be decades old when it finally reaches space.



CONTINUITY OF A CORE TEAM IS ESSENTIAL TO MAINTAINING OLD INSTRUMENTS AND NEW PEOPLE MUST BE ADDED WHEN NEEDED. ON-ORBIT SUPPORT FOR THE LAUNCHED INSTRUMENTS CAN PROVIDE A FOCUS FOR TRAINING NEW PERSONNEL.

It might seem that almost all work related to flying a series of instruments should be finished after the flight hardware is built, with only minimal effort needed later to launch the stored instruments. In reality, maintaining flight hardware for many years prior to flight is a major challenge. The experiences of the Goddard Space Flight Center Polar Operational Satellites (POES) in providing earth-sensing instruments developed for the National Oceanic and Atmospheric Administration for flight on the European Meteorological Operational (MetOp) spacecraft teaches some important lessons about that challenge.

These instruments were procured from Goddard instrument contractors at an average cost of about $14 million for each instrument at delivery in the late 1990s. The last set of these instruments will be almost twenty years old at the time of their planned launched on MetOp-C around 2018.

Programmatic Issues

Some of the issues faced by POES and other projects responsible for launching old instruments are programmatic, relating to how the missions are supported, staffed, and managed.

Obtaining Sufficient Funding

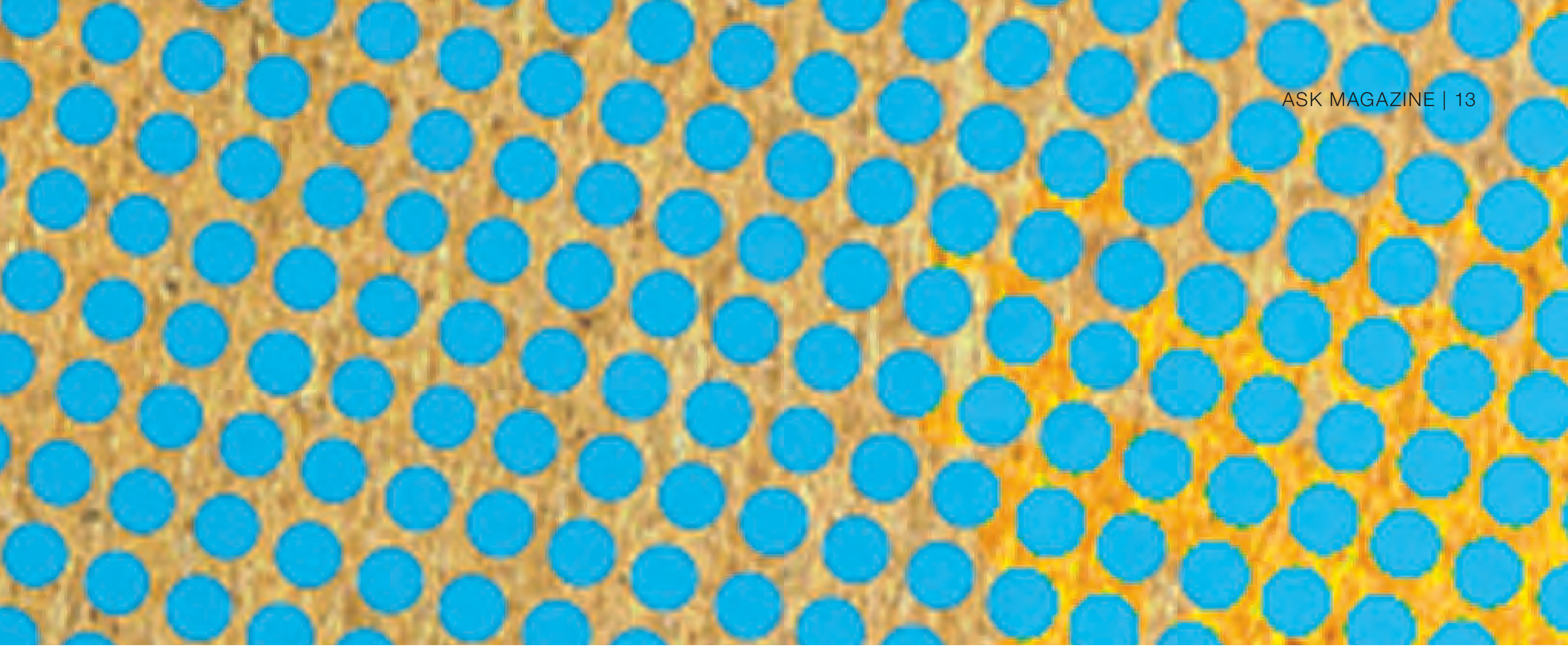
Problem: When a decision is made to develop a series of satellites and instruments, the need for the mission is well defined. Strong financial arguments are made for copies of the same instrument—savings come from having a single design for multiple units and mass parts purchases. Many years later, after all but the last unit of the series are on orbit, it is much harder to obtain needed funding. Typically, the original schedule is out of date and the final launch has been delayed many years. Government managers who started the mission have transferred to other projects or retired, and savings from procuring multiple copies are being eroded by the sustaining engineering costs for the unexpectedly long mission lifetime. Those now responsible for budgets are probably struggling to fund missions currently in development and may be less familiar with the old one.

Mitigation: Decision authorities need to be aware of the problems of flight hardware maintenance and should advocate for the necessary budget. The POES project has addressed this by identifying the increased risks to mission success without the necessary sustaining engineering funding. While it is expensive to lengthen the old mission, its longer lifetime often defers the costs of a follow-on mission to later years.

Retaining Knowledge

Problem: It is difficult to preserve detailed understanding of the design, manufacturing, and testing of flight hardware twenty years after the last unit was delivered. Folks move to new projects, relocate, change employers, or retire. Companies no longer produce spaceflight hardware or go out of business. Records are archived somewhere in yellowing paper or in obsolete, unreadable electronic media. Documentation is incomplete or ambiguous. Important unwritten lessons have been forgotten.

Mitigation: Continuity of a core team is essential to maintaining old instruments and new people must be added when needed. On-orbit support for the launched instruments can provide a focus for training new personnel. The POES project has maintained high-fidelity engineering units on all instrument contracts. They bring their essential expertise to rehearsals for working on the flight unit and investigating anomalies by recreating the test conditions or on-orbit environment. Frequently, the company that provided the unit is developing newer instruments in the same family type and has a pool of skilled individuals who can assist the older project. Key positions in the new project are often filled by veterans of the previous instrument generation. Retirees from the old project have been an excellent knowledge source for the POES project; they often gladly work part time and can support essential activities like prelaunch reviews. Incentives to keep experienced people with the old project include interesting assignments during slow periods, participation in spacecraft-level testing, attending the final launch, and bonuses.



Extending Contracts

Problem: It takes about five years from contract start to deliver the last unit in a series. Assuming another twenty years until the final launch, flight hardware contracts can be active for twenty-five years or longer. Corporate takeovers and mergers as well as changes to major subcontractors and suppliers are likely to affect contracts that old. Company restructuring usually creates new mandated processes and procedures that are disruptive to an old project. Government contract administration is required until the last instrument is launched. The continually updating NASA flight-project requirements need to be evaluated to determine which ones apply to flight hardware built so many years earlier.

Mitigation: Appropriate levels of government contractual, financial, and technical effort are necessary to keep the instrument contracts active. One POES project instrument contract, executed in 1988, has had more than 375 modifications, including several sole-source performance period extensions. General NASA requirements should be grandfathered to when the instruments were delivered unless there is compelling reason and funding to add new ones to the contract.

PROBLEMS WITH FLIGHT HARDWARE RESULTING FROM MANY YEARS ON THE GROUND INCLUDE EXPIRATION OF MATERIALS' SHELF LIVES, LUBRICANT CREEPING FROM BEARINGS AND RESERVOIRS, RELAXATION OF MECHANICAL PRELOADS, CRACKING OF STAKES AND BONDS, AND CONTAMINATION OF DETECTORS BY MOISTURE OR ORGANICS.

Technical Issues

POES and similar projects also have to deal with technical issues related to the age of instruments.

Extended Storage

Problem: Had it been known at project start that the final instrument would be launched twenty years after delivery, long-term maintenance would have been a design requirement. Easy replenishment of limited-life items or storage orientation to minimize gravitational effects are the kinds of measures that would have been taken. Problems with flight hardware resulting from many years on the ground include expiration of materials' shelf lives, lubricant creeping from bearings and reservoirs, relaxation of mechanical preloads, cracking of stakes and bonds, and contamination of detectors by moisture or organics.

Mitigation: Flight hardware should be kept in an appropriately clean, controlled environment. POES project instruments are purged with gaseous nitrogen to minimize the degradation of materials over time. They are activated periodically to ensure they function properly and to exercise motors and mechanisms. If testing before launch indicates that performance has degraded and there is insufficient budget or time for repair, then project leaders must recognize that all instrument requirements may not be met on orbit.

Making Repairs

Problem: If flight hardware is twenty years old at launch, it was probably modified after it was built. Instruments can require rework for many reasons: to correct problems found on earlier units in the series, in response to parts alerts, handling

or shipment damage, test failures, spacecraft interface changes, contamination, overstressing during testing, alignment changes, and other factors. There is risk in repairing an old instrument without skilled people, good documentation, and the necessary ground-support equipment (GSE). A full set of spare parts or assemblies may not be available because they were never originally procured or were installed in earlier flight units. Acquiring new parts for old flight hardware is arduous; parts may no longer be manufactured, may be unaffordable due to minimum lot requirements, or be only available from an unreliable off-shore supplier. The design may contain unique parts developed by a niche company that went bankrupt. Existing parts probably need relife testing. If new parts are used to replace obsolete or unavailable parts, redesign will be necessary. Replacement parts may not fit the original footprint, interfaces, or thermal characteristics. The company's manufacturing capabilities may have been modernized since the instrument was built. For example, surface-mount techniques may be the sole method used today for electronics boards, so repair of boards designed for older techniques may not be possible.

Mitigation: If a problem is minor, it may be better not to risk repairing an old instrument. Spare parts should be replenished when used so that a complete set remains available until the last unit is launched. If repairs are necessary and some parts are missing, aggressive efforts will be needed to locate them. Some parts may still be in stock at the company or within NASA. POES project contractors have acquired new parts suppliers when the original parts were unavailable and undertook the formal flight qualification of the replacement parts.

Updating Ground-Support Equipment

Problem: GSE is often ignored when an instrument waits twenty years for flight. Computers used for structural analysis and to control instrument tests and process science data when the instruments were built probably have been superseded numerous times. Equipment needed for environmental testing, including special fixtures, thermal-vacuum chambers, and thermal-vacuum targets, may not be found.

Mitigation: Implementing a realistic GSE refresh plan is essential. EBay can sometimes be a source of antiquated equipment. The POES project has modernized GSE when sufficient spare parts are unavailable to repair existing GSE.

Meeting the Challenge

As the POES experience shows, maintaining old flight hardware is challenging. A variety of programmatic and technical issues must be dealt with to successfully launch flight hardware decades after manufacture.

Early planning for the possibility that many years may pass before an instrument is launched can help avoid or mitigate problems later on. That may happen to many science missions, not only those that feature instruments built for multiple flights. In today's era of constrained budgets, such delays are likely to be common. The lessons of POES can help those other missions meet the challenge. ●

KAREN HALTERMAN has been the POES project manager since 2001, interrupted by five years starting in 2006 when she served as the Magnetospheric Multiscale project manager.

BUILDING A BETTER TELESCOPE

THE LEGACY OF NASA'S BALLOON MISSIONS

BY DON COHEN

In an article on the NuSTAR launch delay in the fall 2012 issue of *ASK*, I wrote, "NuSTAR, the Nuclear Spectroscopic Telescope Array, contains the first focusing telescopes designed to look at high-energy X-ray radiation." Soon after that issue was sent out, complaints began to arrive: What about the balloon missions with focusing X-ray telescopes that preceded it? Didn't I know about HERO, the High-Energy Replicating Optics mission? Or HEFT, the High-Energy Focusing Telescope? And what about InFOCuS, the International Focusing Optics Collaboration for micro-Crab Sensitivity? Even the names of two of the three made it clear that those pre-NuSTAR missions featured focusing high-energy telescopes.

Antarctica offers a unique environment for long-duration balloon flights, which the International Focusing Optics Collaboration for micro-Crab Sensitivity (InFOCuS) mission hopes to take advantage of in 2014. Here, the Super Trans-Iron Galactic Element Recorder payload prepares for its Antarctic launch.

Photo Credit: NASA

DESIGNING AND BUILDING AN EFFECTIVE DETECTOR WAS ALSO A PROCESS OF TRIAL AND ERROR. BEFORE THE FIRST LAUNCH, SEVERAL PROTOTYPES USING DIFFERENT TECHNOLOGIES HAD TO BE TRIED SO THE RIGHT COMBINATION COULD BE BUILT INTO THE FLIGHT PAYLOAD.

Well, no, I didn't know about them. I'd never heard of them. My mistake. In the online version of the NuSTAR article, we added a qualifier—the first focusing telescopes "on orbit"—to the offending sentence to make it true. I promised to correct the error in a later print issue of *ASK*.

Which is what I'm doing here. But when I began to look into those balloon missions, it became clear that they should have more than a brief mention in a one- or two-sentence apology. They are well worth writing about in their own right. And the way they have fostered expertise and technical advances that made NuSTAR possible and continue to contribute to new missions is an especially rich subject for *ASK*.

Why Balloons?

The drawbacks of balloon-based astronomy are obvious. The missions are very brief compared to the years-long life of orbiting telescopes, many lasting less than a full day. Although the balloons rise high enough to avoid much of the atmospheric distortion and absorption that limits Earth-based telescopes, they do not eliminate those problems entirely. And even the thin atmosphere above 125,000 feet exerts forces that make holding a steady focus on distant objects challenging.

But there are important advantages. The obvious one is cost. Launching a balloon payload costs a tiny fraction of what a rocket launch does. And, unlike an orbital mission, a balloon's gondola and the instruments it contains can usually be recovered intact and used again.

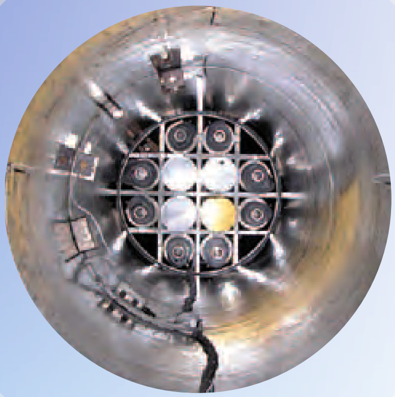
The low cost and instrument reuse make the balloon mission especially useful for testing and improving instruments—as opposed to the orbital-science missions whose instruments need to be as close to perfect as possible before launch. That low cost and the relative frequency of missions also make them ideal opportunities for graduate students in high-energy astronomy to learn their trade—something that the more expensive but budget-limited orbital missions could not accommodate. Brian Ramsey, leader of Marshall Space Flight Center's HERO mission, notes that balloon missions' time scale of a few years is ideal for PhD students. Because of that relatively short span from start to finish and because balloon mission teams are much smaller than the teams responsible for orbital missions, students can be involved in every aspect of a mission.

From HEFT to NuSTAR

Graduate student experience with balloon-based high-energy astronomy brought Fiona Harrison into the field. The desire to build a more sensitive, focusing instrument eventually led to her becoming principal investigator for HEFT, a NASA-sponsored mission carried out by Caltech, Lawrence Livermore National Laboratory, Columbia University, and the Danish National Space Center. Harrison, a professor of astronomy at Caltech, says that HEFT helped develop the technology that eventually made NuSTAR possible.

Proposed in 1995, HEFT's first flight occurred in 2005. The ten years between proposal and launch included four or five years of technology development of the instrument's optics and detectors. A big challenge of imaging high-energy X-rays is that they can only be reflected toward a detector if they strike a mirror at a very shallow angle, grazing the surface like a stone skipping off the surface of a lake. At a steeper angle of incidence, they will penetrate the reflecting material instead. So HEFT's mirrors are conical tubes that focus X-rays that enter almost parallel to their surface. In order to collect enough of the radiation to create a useful image, the telescope consists of several hundred reflecting surfaces nested each within the others, separated by a thin substrate.

The teams originally used aluminum foil as the substrate but that material could not hold its shape well enough to meet the required rigorous specifications. Through trial and error, they eventually settled on a "slumped" glass substrate—extremely thin glass sheets, like those developed for flat-panel televisions, melted into the proper shape over molds (called "mandrels"). Designing and building an effective detector was



View from inside the optical bench of the HERO configuration consisting of eight co-aligned mirror modules, each module containing twelve mirror shells.

also a process of trial and error. Before the first launch, several prototypes using different technologies had to be tried so the right combination could be built into the flight payload.

Without HEFT, there probably would have been no NuSTAR. For one thing, the success of the balloon mission was an incontestable proof of concept that helped convince the committee judging candidate proposals for NASA's Explorer program that NuSTAR could perform as promised. And the HEFT team became the core of the NuSTAR team, bringing their experience and the knowledge it fostered to the orbital mission. So in addition to providing its own science results, like an X-ray image of the Crab Nebula, HEFT was a test bed and training ground for the later mission.

Not all the expertise that made NuSTAR possible comes from HEFT. At Goddard Space Flight Center, Will Zhang was working on slumped-glass substrate for mirrors for the proposed Constellation-X mission (which later merged with the European XEUS, or X-ray Evolving Universe Spectroscopy, project to become the International X-ray Observatory, or IXO). Harrison was lead of the Constellation-X team and thus knew about Zhang's work. She determined that it had advantages over what had been done for HEFT and asked him to make glass segments for NuSTAR, which were then coated and built into mirrors by the same team that built HEFT.

From HERO to ART

Marshall's HERO mission uses a different technology for building its telescopes. Instead of the slumped-glass substrate segments used on HEFT and NuSTAR, it uses electroformed nickel replication to create nickel-cobalt shells that are then coated with a thin reflective layer of iridium. Only 1/100th of an inch thick, the shells are grown in a tank on polished aluminum mandrels. Unlike the slumped-glass substrates, which must be bonded together to make a conical whole, the nickel-cobalt shells are single conical pieces. This allows the HERO technology to provide greater angular resolution—the ability of a telescope

InFOCuS heads above the clouds. At a float altitude of 128,000 feet, the balloon will inflate to 40 million cubic feet, large enough to hold several jumbo jets.

Front view of the High-Energy Focusing Telescope instrument minutes before launch.

to separately image objects at a small angular distance from one another. NuSTAR's optics have an angular resolution of about 50 arc seconds; the angular resolution of HERO's optics is 25 arc seconds. (One arc second is 1/3,600th of a degree of angular measurement.) HERO's mirrors are, however, relatively heavier than glass-substrate mirrors.

HERO took the first focused hard X-ray images of any kind in 2001—images of Cygnus X-1 and the Crab Nebula. It is scheduled to fly next in the fall of 2013 to look at our sun as well as targets outside the solar system.

HERO's superior imaging technology has been used on FOXSI, the Berkeley-based Focusing Optics X-ray Solar Imager, a sounding-rocket mission that flew in November 2012. And the Russian space program is purchasing HERO-like optics for the ART (Astronomical Roentgen Telescope) instrument aboard the Russian-led Spectrum Roentgen Gamma project, an orbital mission designed for an all-sky X-ray survey and scheduled for a 2014 launch.

The Ongoing Legacy

Jack Tueller, principal investigator for InFOCuS, describes the "enormous technological evolution" that has characterized that mission (a collaboration between Goddard and the University of Nagoya), which launched its first balloon-borne telescope in 2001. As was true of HEFT and HERO, the InFOCuS team had to work toward the design of an effective instrument. Some of the early versions of nested reflective surfaces would "crinkle up," says Tueller. Commenting on the trial-and-error opportunities offered by balloon missions, Tueller adds, "The risk is less than for orbital missions. If it's not successful, you get the payload back and fly it again."

InFOCuS continues to develop. X-Calibur, a new instrument that will detect the polarization of X-ray, will fly by 2014. And the InFOCuS team is investigating long-duration flights that would be launched from Antarctica, where wind patterns and 24-hours-a-day summer sunlight make the long flights possible. Thirty-day flights have occurred and a newly designed high-pressure balloon might stay aloft for more than one hundred days. That, notes Ramsey, could make them a low-cost competitor with orbital missions.

A new pointing system that can keep balloon-based telescopes aimed at distant objects with unprecedented accuracy should also contribute to the scientific value of future missions. The Wallops Arc Second Pointer (or WASP), developed at NASA's Wallops Flight Facility, can steadily aim a telescope at an object or area a single arc-second wide. Ramsey hopes that WASP will be used on a future "Super-HERO" mission.

InFOCuS also currently features a rigid telescope 8 meters long, something not possible in the confined payload space of existing orbital launch vehicles. But what scientists and engineers learn from that instrument can guide future orbital missions that have a deployable folded version of an instrument of similar size.

Zhang's continuing work on slumped-glass-based mirrors will also serve future missions. Currently, he is able to produce substrates with approximately ten times the resolution of NuSTAR's instruments. The challenge here is whether they can be built up into a full optic and retain the good performance. The technology was expected to be used in IXO. That mission has been canceled, but the technology is ready for the future application that will come and will bring with it new discoveries.

The story of these past, present, and future missions shows how technological progress happens. Instruments become increasingly sophisticated and powerful by incorporating and improving on the achievements of their predecessors. That improvement is possible because of the openness of scientific and engineering communities to share with and learn from one another. There is competition, Zhang admits, but, he says, "We compete and cooperate." Communication is key. "We go to the same conferences," says Zhang. "We read and publish in the same publications; we hear things through the grapevine." And they share the same goal: a fuller understanding of how the universe works. ●

… LOW COST AND THE RELATIVE FREQUENCY OF MISSIONS ALSO MAKE THEM IDEAL OPPORTUNITIES FOR GRADUATE STUDENTS IN HIGH-ENERGY ASTRONOMY TO LEARN THEIR TRADE—SOMETHING THAT THE MORE EXPENSIVE BUT BUDGET-LIMITED ORBITAL MISSIONS COULD NOT ACCOMMODATE.

Brian Ramsey, lead scientist for the High-Energy Replicating Optics program, installs the mirrors that in May 2001 collected the world's first focused high-energy X-ray images of any astronomical object. The Marshall-fabricated mirrors, a special type called "grazing incidence," are nested cylinders with extremely smooth inner surfaces that reflect high-energy X-rays at very shallow angles.

Photo Credit: NASA Marshall Space Flight Center

PRECISION &
BUILDING NUSTAR'S MIRRORS

Many NASA projects involve designing and building one-of-a-kind spacecraft and instruments. Created for particular, unique missions, they are custom-made, more like works of technological art than manufactured objects. Occasionally, a mission calls for two identical satellites (STEREO, the Solar Terrestrial Relations Observatory, for instance). Sometimes multiple parts of an instrument are nearly identical: the eighteen hexagonal beryllium mirror segments that will form the James Webb Space Telescope's mirror are one example. But none of this is mass production or anything close to it.

Photo Credit: NASA/Chris Gunn

Niko Stergiou, a contractor at Goddard Space Flight Center, helped manufacture the 9,000 mirror segments that make up the optics unit in the NuSTAR mission.

EFFICIENCY

BY WILLIAM W. ZHANG

The mirror segments my group has built for NuSTAR, the Nuclear Spectroscopic Telescope Array, are not mass produced either, but we make them on a scale that may be unique at NASA: we created more than 20,000 mirror segments over a period of two years. In other words, we're talking about some middle ground between one-of-a-kind custom work and industrial production.

Mirrors for NuSTAR

The mirror segments of NuSTAR's two X-ray telescopes are made from thin glass sheets coated in alternating layers a few atoms thick with silicon and tungsten. They focus hard X-rays that glance off those reflecting surfaces at an extremely shallow angle. To capture sufficient X-rays to ensure high-quality images, the mirror segments are nested one inside the other—a total of 133 concentric shells of mirrors for each telescope. To create the mirror segments, sheets of glass are placed atop molds, or mandrels, and heated until they "slump" to the required shape.

I have been developing and perfecting the process for forming these mirror segments for more than a decade. My coworkers and I first had to find a way to prevent the glass sheet from sticking to the mandrel surface at the slumping temperature: 600 degrees centigrade. After investigating a number of materials, we settled on a boron-nitride slurry that is widely used in industrial casting processes. The specific challenge we had to meet was to smooth the boron-nitride release layer so that it does not create a texture on the finished glass segments. Any texture or roughness on the glass surface would result in scattering that would degrade X-ray image quality.

Many trials and errors led us to a procedure that smoothed the initially rough boron-nitride surface to a mirror finish. Then we had to reengineer the interior surfaces of commercially procured electric ovens to create a clean environment, because any particulates in the oven could be trapped between the glass sheet and the mandrel surface, creating craters on the finished mirror surface and degrading image quality. Fortunately, we were able to find a ceramic slurry that, after being sprayed on the interior surface and a bakeout, dries into a smooth and clean surface, very much like glazed ceramic tiles. Finally we had to map the temperatures inside each oven to ensure they would provide a uniform heating environment so the glass sheets could slump in a controlled and gradual way. Any "wrinkles" inadvertently introduced would lead to permanent error on the finished mirror segment.

NuSTAR required a total of nearly 9,000 mirror segments: just under 3,000 for each of the two telescopes that would fly on the spacecraft plus another 3,000 for a spare. To make sure we could guarantee to provide that many, and given the inevitability of breakage and other losses during the many steps between their creation and their finally being integrated into the telescopes, we decided to produce 20,000. Of those, we shipped 15,000 to the Danish Technical University in Copenhagen and Columbia University in New York City, where they were coated with multilayers and assembled into the two telescopes.

The challenge was not only producing these delicate components to the necessary rigorous specifications but also doing so within the constraints imposed by a stringent project budget and schedule. We needed to combine the precision of custom work with the efficiency of something like industrial mass production. That meant honing the process to make each step as efficient, simple, and reliable as possible. For example, we reduced the amount of time required to smooth the boron-nitride coat from fifteen weeks to less than eight weeks. We also had to optimize the temperature cycle of the oven to reduce the overall amount of cycle time from thirty-one hours to less than sixteen hours, so the process could be completed overnight. This reduction was absolutely essential to meet the project schedule.

I knew we needed savvy, hands-on people to do the work. Practical experience with handling materials—a sense of the "feel" of things—was much more important than theoretical knowledge. Fortunately for us, a nearby automotive shop was downsizing as a result of the recession. We quickly picked up six of their technicians who fit the bill.

PRACTICAL EXPERIENCE WITH HANDLING MATERIALS—A SENSE OF THE “FEEL” OF THINGS—WAS MUCH MORE IMPORTANT THAN THEORETICAL KNOWLEDGE.

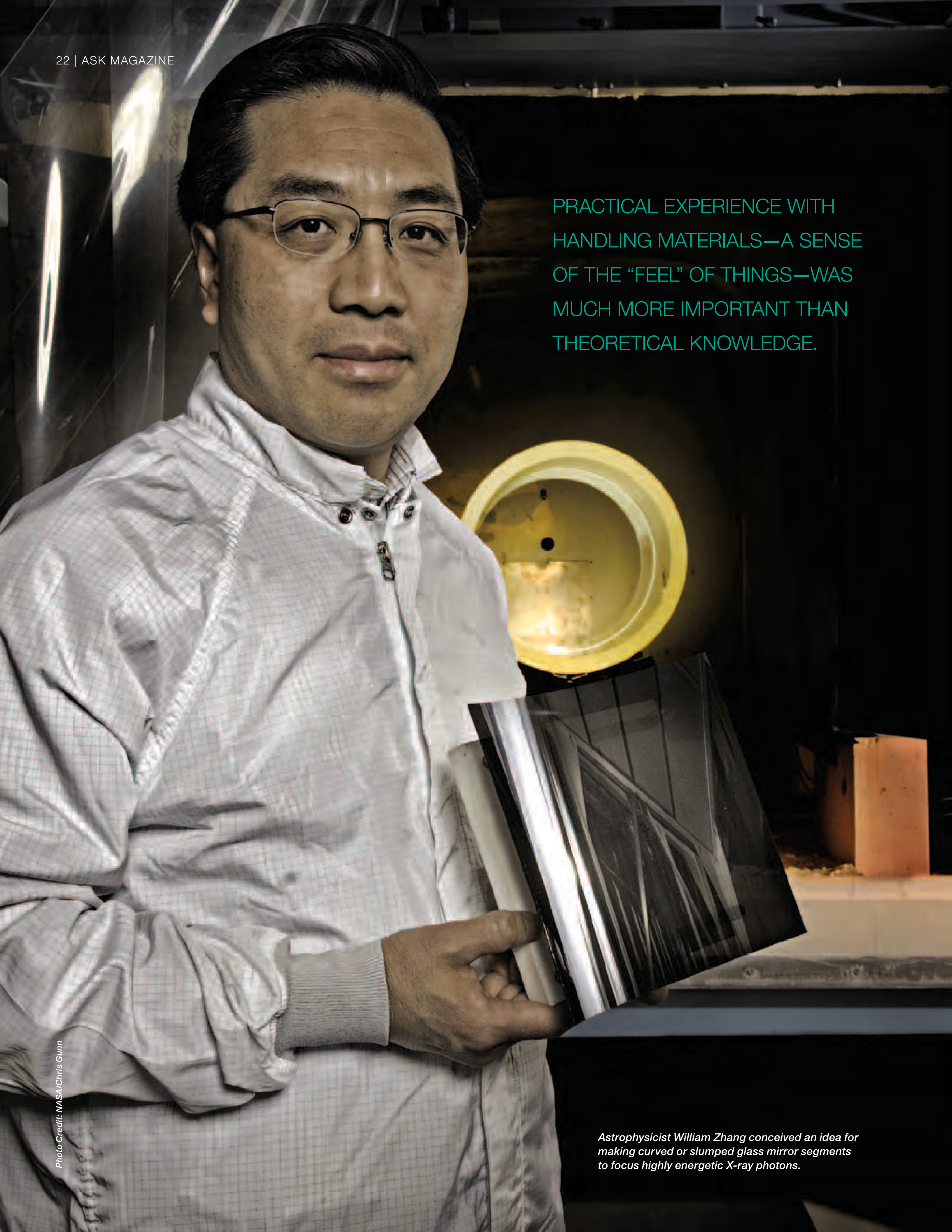
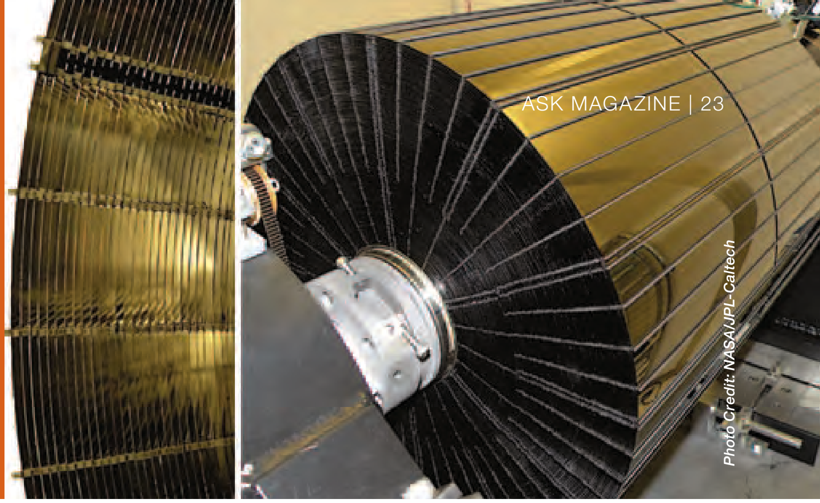


Photo Credit: NASA/Chris Gunn

Astrophysicist William Zhang conceived an idea for making curved or slumped glass mirror segments to focus highly energetic X-ray photons.



Different views of one of two optic units onboard NuSTAR, each consisting of 133 nested cylindrical mirror shells as thin as a fingernail. The mirrors are arranged in this way in order to focus as much X-ray light as possible.

In February 2008, Goddard management made available to us a warehouse to use. We had to clean it and create a clean room and buy ovens and other equipment. Then our team had three months of training. The training of a new worker starts with familiarizing him or her with handling the 0.21-mm-thick glass sheets. Typically during the first two weeks on the job, a worker would break a number of mirror segments. Miraculously, workers rarely broke a mirror segment once they got the knack of handling it. The training ends with the worker being able to work independently, from operating ultrasonic cleaners to programming electronic oven controllers and cutting the thin glass mirrors with a nearly 100-percent success rate. In the spring of 2009, we began cranking out mirrors. We finished in early 2011, slightly ahead of project schedule and 10 percent under budget, saving more than $500,000 for the project.

The entire manufacturing process was not without surprises, however. In the summer of 2009, for instance, we found that some mirror segments had unacceptably high microroughness. We quickly traced this problem to a detergent we were using to clean the glass sheets in ultrasonic cleaners. The particular batch of detergent was exceedingly alkaline and was chemically etching the glass sheets, compromising the pristine, extremely smooth surface that is required. We quickly implemented a procedure to monitor the pH of the ultrasonic solution and the time that each glass sheet is soaked.

Continuous Improvement

Three quantities define the power of a telescope. One is angular resolution, or the ability of optics to image objects located at a small angular distance from each other as separate. Another is total photon-collecting area. The third is energy bandwidth—the range of photons of different energies a telescope can focus.

Given the budget limitations and related mass limitations of small Explorer missions like NuSTAR, the collecting area of an orbiting X-ray telescope is essentially fixed. Bandwidth is relatively fixed as well, limited by the physics of mirrors and detectors. So the one place that has significant room for improvement is angular resolution, which is largely a function of the precision of the mirrors. That's what we've been working on since the completion of our work for NuSTAR.

We have made improvements in all three areas involved in making these telescopes.

Substrate. We are now making the mandrels more precise. For NuSTAR, we formed two or three layers on each mandrel and distorted them slightly to fit one within the other. Now each layer has its own mandrel. More than doubling the number of molds has required us to lower the price of each by 50 percent. For a future mission we are working on reducing the cost of making mandrels so that, for the same budget as NuSTAR, we expect to be able to make two to three times the number of mandrels.

Coating. The NuSTAR substrates were coated with silicon and tungsten in alternate layers, each approximately 30 angstroms thick. That coating was somewhat "stressy" (meaning the coating exerted stress on the substrate) and therefore distorted the glass slightly when it was applied. We have now developed and optimized an annealing process that can effectively relieve all the coating stress, resulting in the preservation of the substrate figure.

Assembly. In assembling the NuSTAR mirrors, colleagues at Columbia University had to force them into shape to fit them together. Now, more precise mirror shapes and improved assembly techniques have eliminated most of the distortion that process created. In the new process we have developed, each mirror segment is attached to the housing at only a small number of discrete locations, resulting in less constraint and distortion.

Taken together, these improvements reduce distortion by a factor of ten, leading to significantly better angular resolution. NuSTAR's telescopes have an angular resolution of 58 arc seconds. (An arc second is 1/3,600th of a degree.) We expect future telescopes to achieve an angular resolution of better than 10 arc seconds.

These new telescopes will fly first on a balloon or a sounding rocket. In the future, orbiting on a NuSTAR-like spacecraft, they will be able to see fainter objects farther away in space and further back in time, adding to our growing knowledge of the nature and origin of the universe. ●

WILLIAM W. ZHANG is an astrophysicist at Goddard Space Flight Center. In addition to his work for NuSTAR, he is leading a group of scientists and engineers developing lightweight and high-angular-resolution X-ray optics for future NASA missions.

The Hitchhiker's Guide to Software Engineering at NASA

BY HALEY STEPHENSON

Using a wiki platform, the NASA Software Engineering Working Group has set a new precedent for collaboratively authoring, reviewing, and enabling interactivity for handbooks at NASA.

The 135 software engineering requirements for NASA projects are listed in a small, blue booklet, seventy pages long, called NASA Procedural Requirement (NPR) 7150.2. It is one of many NPRs at NASA for disciplines including finance, launch services, legal, human resources, and program/project management. They are the "how to and must do" for work at NASA.

An inherent challenge of writing NPRs is stating *what* is required to readers without detailing *how* those requirements should be implemented. Make it too prescriptive and they might discount better-suited processes for their project. Too brief and they are left uncertain. In the case of 7150.2, almost every requirement is one sentence long. For instance, requirement 2.4.1 on software verification reads, "The project shall plan software verification activities, methods, environments, and criteria for the project." This single line of text is followed by a brief note and then requirement 2.4.2, software validation.

IT'S AS IF ALL OF A SUDDEN NASA REALLY KNOWS WHAT IT KNOWS.

"We [kept] it pretty lean," said John Kelly, NASA's program executive for software engineering, who was involved in devising the requirements, "but people were asking us for more information."

The solution: write a handbook. A sort of hitchhiker's guide to the NPR, a handbook doesn't impose additional requirements; it's meant to be an assist. One prominent and highly regarded example is the *NASA Systems Engineering Handbook* (NASA/SP-2007-6105), which sits on the bookshelves and desks of systems engineers at NASA and beyond. The NASA software engineering community voiced their need for a similar resource. Their leadership responded with an electronic, browser-based handbook run on a wiki platform—a dramatically different approach for collaborative authorship and review that has sparked interest across NASA.

"Somebody described it almost as a knowledge capture type of activity," remarked Kelly on the process of creating the handbook. "It's as if all of a sudden NASA really knows what it knows."

Not Wikipedia

In 2011, on a detail to the Office of the Chief Engineer at NASA Headquarters, Glenn Research Center's Kevin Carmichael was assigned by Kelly to lead the development of NASA's first-ever *Software Engineering Handbook* (SWEHB).

Typically, creating and updating a handbook is a complicated and time-intensive process involving a plethora of e-mails, edits, version control, and spreadsheets called comment-resolution matrices. It can take years.

But the SWEHB wasn't to be the usual handbook. Inspired by mobile apps and e-magazines, the software engineering working group leadership wanted the handbook to be electronic. To help refine their options, a member of the group brought in a web-savvy young professional from Goddard Space Flight Center, software engineer Jon Verville.

Verville took the initial concept for the handbook and built on it to arrive at a robust and flexible solution. "It needed to be something that was broadly accessible, irrespective of platform—you know, mobile, desktop, laptop," he explained. If you have the Internet, you can access the handbook, whereas selecting a proprietary solution or singling out a particular type of hardware like an iPad would limit that accessibility. Instead, Verville recommended a browser-based solution built on a wiki platform.

THEY COULD GET WHAT THEY NEED AT THE REQUIRED LEVEL OF DETAIL AND GET BACK TO WORK, OR SERENDIPITOUSLY DISCOVER OTHER USEFUL INFORMATION …

"For a lot of us, 'wiki' meant Wikipedia," said Carmichael. "We all had some familiarity with that, but we didn't see how it translated into what we were trying to do."

The proposed wiki platform wouldn't look like Wikipedia but it would have similar functionality. It would enable collaborative authorship of the handbook by a defined group. Furthermore, the platform provided simple, yet powerful features such as commenting, revision tracking, database capability, and hyperlinking. For example, publications often reference outside materials that are useful, but perhaps not easily found. "Then it's an exercise for the reader to hunt that down, and it can be time consuming," Verville said. "It's just one more of these little hurdles that people encounter while trying to find the information they need." Providing direct hyperlinks to online resources significantly reduces this barrier.

If a hyperlink or a reference changes, that's okay, explained Verville. In paperback, a reference would have to be located everywhere it appears in the handbook, updated page by page, and reprinted. The wiki's database feature could accomplish the same goal with a few keystrokes and the click of a button.

Additionally, the platform would allow users to select a requirement from the directory or search for it. They could get what they need at the required level of detail and get back to work, or serendipitously discover other useful information that might help them further. Inside the wiki-based handbook Verville proposed, requirements like the aforementioned 2.4.1 on software verification would have a richer, more accessible story to support them.

Convinced, Carmichael and the SWEHB team dubbed Verville the handbook's architect and committed to using a particular wiki platform called Confluence.

The Beta Handbook

Each section of the SWEHB provides six areas of information per entry: the requirement, its rationale, guidance for implementation, notes for small projects, associated resources, and related lessons learned.

The authoring team consisted of seven members, amounting to three and a half full-time employees, distributed across Tennessee, West Virginia, Pennsylvania, and Washington, D.C. They met in person only three times over the two and a half years they worked together and primarily coordinated through weekly teleconferences. "This was the first time that I managed a distributed team like that," said Carmichael. "It worked exceedingly well."

The team came up with a six-step process for authoring and releasing each part of the handbook for review. Throughout each step, a built-in work-tracking system monitored their progress so they could all see who was working on what and if the work was under way, completed, or not yet started. The process steps were the following: author a section, send it to a technical writer for review, send to Carmichael for review, send to Kelly for review, then a final review by the

section's original author, and then post the content to the wiki online.

This didn't make the content final, however. The final version of the handbook would have to undergo a technical working group review, an agencywide review, an Engineering Management Board review, and then receive final approval from NASA Chief Engineer Mike Ryschkewitsch. If the SWEHB were printed, this would have meant months to years before practitioners would be able to see any part of it. But the SWEHB wasn't printed, so Carmichael and his team had another idea.

"We had a lot of people who wanted help; they wanted guidance immediately. They didn't want to wait two and a half years," said Carmichael. "So we put stuff out there and we just called it 'beta.'" This meant that anyone at NASA could see the SWEHB being built from the ground up, section by section.

> "THAT WAS A DIFFERENT WAY OF DOING THINGS," SAID CARMICHAEL. "WHENEVER WE MADE EDITS … PEOPLE COULD SEE THEM IMMEDIATELY."

The beta handbook's rigorous six-step authorship and collaborative review process provided its contents an acceptable level of pedigree. Making the beta version available online also enabled anyone in the agency to review it and provide input in the form of comments on any of the published pages. Approved edits were made quickly and a team member would e-mail the individual who suggested the change to make sure the revision met their initial intention. "That was a different way of doing things," said Carmichael. "Whenever we made edits … people could see them immediately."

"In an old process, you couldn't do that. It would have been so labor intensive that all this interaction would have been impossible," said Verville. "For instance, in one month, we received over one hundred comments from software experts across NASA, our team made over three hundred approved online edits, and we had over two thousand visits to the site from our review team. There is no way this could be replicated through anything but the web."

Posts and Threads

When the team pushed out the call to review the handbook, reviewers were given the option to put their comments into a spreadsheet and e-mail them back or post their comments directly to the bottom of the appropriate wiki page. Carmichael estimated that less than 3 percent of the comments were delivered by spreadsheet.

"The vast majority of people found it to be much easier to put comments directly into the wiki, and people fed off other people's comments, so it became a good discussion," said Carmichael.

Throughout the review process, members from all ten centers used the commenting space available at the bottom of every page of the handbook to provide their input. In total, nearly eight hundred comments were collected.

"There's a little bit of threading here," said Verville, pointing at his computer screen while clicking through a section of the handbook's comments. "See, this person at Johnson responded to this person from Dryden …. It's very contextual. You're leaving a comment right on the page where you're reviewing the information, and so when other people went to review it, it wasn't about the whole handbook. It was on this particular section of 135 sections where they were putting their comments."

"The inputs we got were fabulous," Kelly said about the commenting feature. "That made it so much richer than just

YOU CAN GO TO ONE PLACE AND BOOM, IT'S ALL THERE. THE KNOWLEDGE OF HOW YOU DO THINGS—HOW TO SUCCESSFULLY DO THINGS.

one person pounding away [on revisions] and not being able to reap some of the inputs from various people who contributed to the wiki environment."

A Paradigm Shift

The SWEHB is the first of its kind at NASA. Approved by Ryschkewitsch on February 28, 2013, the handbook serves as a successful test case for authoring and reviewing handbooks in a digital environment. Throughout the process, the wiki approach was met with some skepticism and caution, as it did not follow NASA's traditional print-publication process. As a result, the team worked diligently to gain stakeholder trust and buy-in to accommodate their electronic process, while ensuring the SWEHB would meet NASA's requirements without compromising its standards.

Interest in capturing organizational or community knowledge using a wiki platform is growing among groups internal and external to NASA. Within NASA, the SWEHB team has been approached by a number of groups who are interested in learning from their process and implementing it in their own organizations. Outside NASA, the Department of Defense sponsored a global collaboration among members from dozens of organizations to create the *Systems Engineering Body of Knowledge* using a similar platform. They released their final version in late 2012.

The handbook is also representative of how the next generation of employees at NASA will work, explained Carmichael. Like the introduction of e-mail or social media into the workplace, implementing a new or unfamiliar paradigm is often met with some resistance. "Younger people in the agency will readily adopt stuff like this. The software engineering community will readily adopt electronic media like this," said Carmichael. However, because the SWEHB is not a book that sits on a shelf or a physical document, Carmichael anticipates the agency will see somewhat of a transition period for current employees—especially those who are more comfortable with traditional handbooks—to acclimate to this particular electronic resource and the others that are likely to follow. "It'll take time to overcome that," Carmichael said.

In May 2013, a version of NASA's SWEHB will be made publicly available online at swehb.nasa.gov. This will be beneficial to NASA and its international, industry, and academic partners who build components integrated into NASA missions. If those components have software, they must meet 7150.2. "They have a big interest in knowing what's in 7150.2 and the reasons behind the different requirements," explained Verville. "So there's a big [potential] for people who are our partners to get something out of this as well, maybe have feedback or have a stake in it being relevant to them, and for them to be able to comment on it, too."

"It's a nice canned resource for people to pull information from," said Kelly. Typically, if someone had a question about a requirement or topic, they'd have to track someone down to find what they needed to know. The handbook offers an alternative. "You don't have to know somebody to ask something and get something in a real piecemeal fashion," explained Kelly. "You can go to one place and boom, it's all there. The knowledge of how you do things—how to successfully do things.

"It's a lot easier than me fumbling through my files in my office," laughed Kelly. ●

Find the Software Engineering Handbook *online at swehb.nasa.gov, or by scanning this code.*

INTERVIEW WITH Don Pettit

BY KERRY ELLIS

Astronaut Don Pettit began his career with NASA seventeen years ago and has since flown on three spaceflight missions. Logging more than 370 days in space and over 13 spacewalk hours, he lived aboard the International Space Station for five and a half months during Expedition 6, was a member of the STS-126 crew, and again lived aboard station for six and a half months as part of the Expedition 30/31 crew.

ELLIS: What led you to pursue a career as an astronaut?

PETTIT: As a little kid I remember John Glenn flying, like so many people my age. That sat a bit in my mind: wouldn't it be neat if I could fly in space? Then I forgot about it for twenty years and studied what I was interested in. I did not consciously change my course of study with the idea that it would make me more attractive to NASA. And I tell students this when they ask me what they should study. You need to do something technical that speaks to your heart and excel at it. When I was getting out of graduate school, I suddenly realized I was qualified to fly in space.

ELLIS: What additional advice do you give students?

PETTIT: You have to take the hard subjects in school and be really good at math and science and engineering. The reason for this is human beings aren't meant to go into space. If you put a human being in space, you need machines to take you there, keep you alive, and bring you home, so you need to understand how those machines work and how to fix them. Your life depends on that.

ELLIS: You also play several roles as an astronaut: engineer, scientist, doctor ...

PETTIT: You are absolutely right. Jack of all trades and master of a few comes to mind. Our crew size is small yet we have a large number of specialties. If you had a crew size of twenty-five, you could have a cook, a surgeon, a mechanic, an electrician, a navigator. You could have all these specialties. But when you have a crew size of six, almost everybody has to be able to do medical, navigation, and cooking. But people gravitate toward things they like to do. For example, André Kuipers was on our mission, and he's a medical doctor. When it came time to draw blood, he did his own and then drew everybody else's. Even though I was trained to draw blood, I didn't have to do it much during the mission—which was great because one of the reasons I'm not a medical doctor is I don't like sticking people. I gravitated toward keeping the galley in shape and making sure we all had food deployed in a manner we could eat and weren't running out of things. Any of us could have done it, but I started doing it at the beginning and kept it up for the whole mission.

ELLIS: You also took on blogging during that mission.

PETTIT: I like to write. I have a hard time writing something meaningful in 140 characters, so my style is to write three or four pages at a time instead of for Twitter. Blogging fit my style. Blogging and tweeting are personal, not a piece of being a crew. If you're interested in doing it, you do it.

ELLIS: Great way to reach the public.

PETTIT: It is. And at the same time it's meaningful. For the diary of a space zucchini, I was telling a story from the view of a third person who was part of the crew while also taking time to weave in the technology needed to keep space zucchini alive, and the trials we had to go through, such as lighting and not having dirt. I started to compost food and use the liquid from the compost in an aeroponic potting system I cobbled up to keep the plants alive.

ELLIS: Was space zucchini your favorite experiment during the mission?

PETTIT: Yeah. There are programmatic experiments—the ones that justify the work on space station—that come up from the ground and are well thought-out and well-planned. There are principal investigators on the ground and we, the astronauts, are more like glorified graduate students doing the experiment on their behalf. The stuff I did, like space zucchini, I like to call opportunistic science. It's science of opportunity.

We do this in research labs on the ground: you do your programmatic science, and while you're there and have off-duty time, you may get an idea. Since you have a lab in front of you, you do an opportunistic experiment on the side. A lot of times these things fail, but every once in a while something really neat will come from these opportunistic experiments. And at ground laboratories, they often are the roots for writing a proposal and getting funding to become future programmatic science. Many times the real advances—the eurekas—come from the opportunistic science. Knowing that is how science is advanced on Earth, I use that model on station. I do the programmatic science for the principal investigators, using all the facilities and expendable resources how they want. Then in my off-duty time, I use extra things, like food and water, little bits of wire, and maybe a few things I brought up in my personal kit to do scientific investigations of my own design. Simply because I was there and I could.

ELLIS: Did any of the experiment results or behaviors surprise you?

"IF YOU PUT A human being IN SPACE, YOU NEED machines TO TAKE YOU there, KEEP YOU alive, AND BRING YOU home, SO YOU NEED TO understand HOW THOSE machines work AND HOW TO fix them."

PETTIT: Yes. All the time. For example, I had a weekend coming up with some off-duty time scheduled, and I got permission to use one of the research freezers that wasn't currently occupied. What an opportunity. Now I could investigate things at cold temperatures. So I made ice cubes, and then I looked at the ice cubes under polarized light to see the interlocking crystal grains and how the single crystals of ice formed—their morphology. I made hundreds of these ice wafers and took pictures both in white light and polarized light, and there's some interesting behaviors. It's going take months to go through these images, look at the crystal structures, and see whether there's anything unusual about how ice freezes in a weightless environment.

ELLIS: Are there challenges to doing science experiments in space?

PETTIT: The people who are proposing programmatic experiments have never been into space. They're using creativity and imagination to figure out what would be a good space experiment, but in space the behaviors are foreign to our Earth-mode intuition. We can think of things that someone on the ground would never have thought about. The work that I call symphony of spheres is a great example. Before I'd done this experiment, if I wrote a proposal to NASA and said I'm going to make a fixture of water and put a bubble in it and look at droplets bouncing around in the bubble, I'd be laughed out of the room. You'd never get funding for that. But when you're on space station, you can make a hemisphere of water and put a bubble in it, then inject it with droplets and just see what happens. That in turn advances a whole new series of experiments looking at droplets colliding on the interface and the potential for mass transfer across the interface. It's something that you'd never think about doing if you're living on the ground and you've never been in space, but once you get there, these things just come to you.

ELLIS: What else about your perspective has changed as a result of being in space?

PETTIT: You can use the whole volume of your living space. You can sit on the ceiling. You can set your computer on the ceiling. Or you can just free-float and type on your computer. We originally could put a laptop on a desk attached to the wall of space station so we could type as if we were on Earth. We had been provided a desk on a frame that clamps to the wall, so we could put a laptop on it, then float up to it and put our feet under a handrail to hold us in place, and we could sit there and type. That's just like we use laptops on Earth. But what we discovered is we don't need the desk. We can just fold the laptop in the shape of an L and stick it on the wall with Velcro. But because we're Earth polarized, we think we need to put our laptop on a desk. So they make desks for us to put our laptops on. After a while, you realize you don't even need to have a laptop stuck to the wall. You can just free-float with your laptop. We can free-float and type, and if you get close to the wall, you just give it a push with your finger and keep bouncing around like a slow-moving asteroid in a video game. Being Earth-centric, you think you need your computer on a desk; then you realize you don't need a desk, just a wall; then you go one stage further and realize you don't even need the wall.

ELLIS: What else have you learned?

PETTIT: There's all kinds of lessons in terms of how you design something. How many different screws do you specify torque for, and how many screws do you just say get good and tight? Some things are overly complicated and should be simplified. Some things are too simple and should be made more complicated. There's all kinds of lessons to be learned in terms of how to best equip the crew for getting their work done.

ELLIS: For example?

PETTIT: This was something that happened during my mission. I would have one activity that was maybe two hours. But it wouldn't show up on the timeline as a single two-hour activity; it would show up as eleven little slices of things that needed to be done, and I was obligated to open and read all eleven slices. There might be a five-minute slice of time and it might take me five minutes to open the slice just to read it. The overhead of taking a single activity and slicing it up into eleven separate pieces impedes your ability to get a task done. So I talked with the ground about the issue and they were able to fix it so a single activity would appear as a single activity, and you wouldn't have a fragmented instruction set. We worked together to fix the problem, and after that we had streamlined activities that would be easy to read and orchestrate.

ELLIS: They were able to fix the issue while you were still on mission?

PETTIT: Yes. We have flight director meetings every week where you talk to your flight director and tell him the good, the bad, and the ugly of what went on that week. They listen to you and then they in turn will tell you the good, the bad, and the ugly of things that you did. We work together. Crews try to become more efficient in terms of interacting with the ground, and the ground tries to become more efficient at working with the crew. You have a subteam on orbit—the crew—and a subteam on the ground—mission control—but all together you work in concert as a team that transcends both Earth and space.

ELLIS: So being an astronaut requires not only hard training but also being generally curious and willing to learn?

PETTIT: That, and you have to be able to laugh when a change comes about because change happens all the time. NASA changes the name of the game. We don't do everything the way we learned two years ago because now things have changed. This happens all the time—both in training on the ground and on your space mission. It's just the way of life when you're dealing with the frontier. Space station is in a frontier. It's a place where mistakes can cost you dearly. It's a place that's rich in discovery.

ELLIS: What do you enjoy most about being part of that frontier?

PETTIT: I like all phases of it. The training is long and arduous, but it's the next best thing to flying in space. And flying in space is what our job description is. Training can be grueling. It can wear you out over time, but it is blissful fun. Because after you do all this training, you get to fly in space. It doesn't get any better than that.

ELLIS: What's the most difficult part of being on that frontier?

> **BEING Earth-centric, YOU THINK YOU NEED YOUR computer on a desk; THEN YOU REALIZE YOU don’t need a desk, just a wall; THEN YOU GO ONE STAGE FURTHER AND REALIZE you don’t even need the wall.**

PETTIT: The most difficult part, and this is always the same answer, is being away from your family. I call it the explorer’s dilemma. When you are home with your family, you have this desire to journey off to the frontier. And when you’re in the frontier, you have this intense desire to be with your family.

ELLIS: Is it any easier with Internet on station?

PETTIT: Actually, we don’t have Internet on station. We have a pseudo-Internet. We have e-mail, but it’s not continuous. We get e-mail drops during the day. I send an e-mail out in the evening, and it might be a day or two before I get an answer. But we have great communication. We get a two-way video meeting with our family once a week, so you can stay versed with what’s happening with your family. My sons were doing a piano recital during a mission and NASA was able to uplink the video so I could watch them. We have stayed connected now in this era better than any time in the past. Even though you are away from your family, you can maintain this long-distance connection. And perhaps that’s the next best thing to being there.

ELLIS: What’s coming next for you?

PETTIT: I’m just starting on my ground assignment. I’m flying a desk right now, in NASA vernacular. And I’m back in line for spaceflight. I still meet all the medical requirements and I’m interested in flying again, so I’m in line. It’s a long line, and it’s moving slow. But it’s a good line to be in. ●

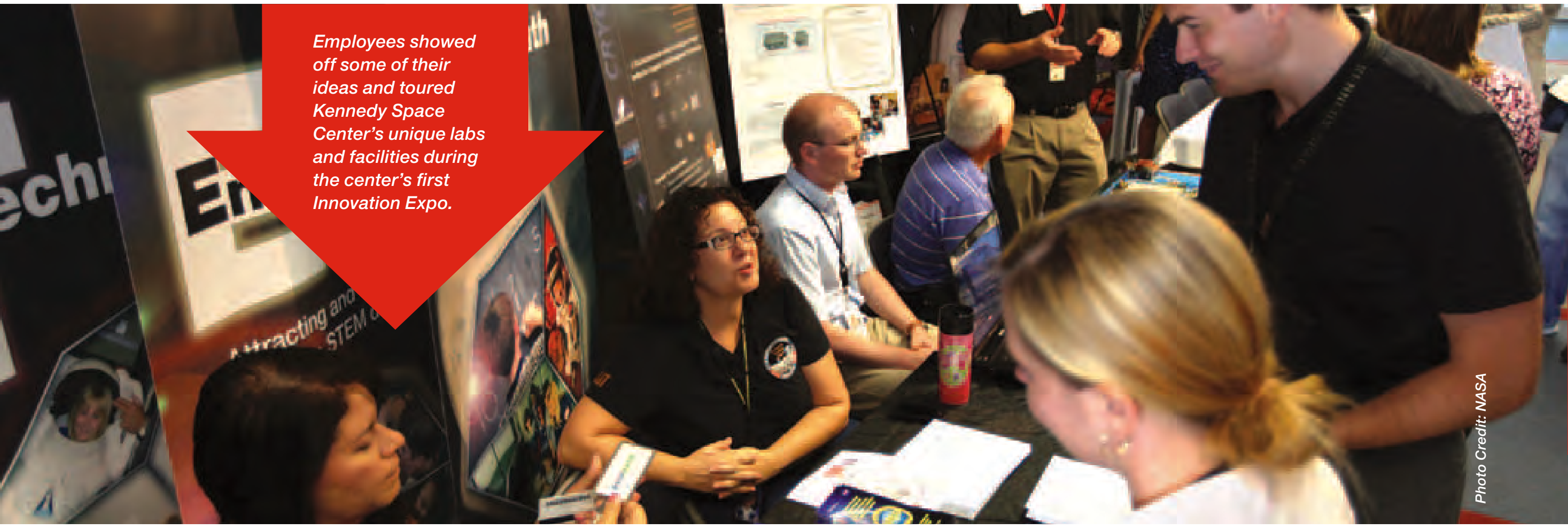
SPACEPORT INNOVATORS

KNOWLEDGE SHARING AS THE GATEWAY TO INNOVATION

BY DAVID J. MIRANDA

Photo Credit: NASA/Kim Shiflett

A robot built by Florida Robotics served as the centerpiece of the exhibit by Kennedy's Environmental Management Branch.



Employees showed off some of their ideas and toured Kennedy Space Center's unique labs and facilities during the center's first Innovation Expo.

Photo Credit: NASA

In 1980 3M brought one of the most famous products in the company's history to market. The Post-it note became a breakout success and is today a staple of the modern office. How it made it to market is a classic story in the history of American innovation. The key component of the Post-it was the weak adhesive that allowed it to stick but also be easily removed. When this weak adhesive was first developed in 1968, no one could find a use for it. In search of a use, its inventor presented the glue at formal and informal knowledge-sharing events at 3M over the course of several years. In 1974, Art Fry happened to hear about the glue at one of these knowledge-sharing seminars. During his church's Sunday service later that week, Fry was frustrated when the small paper strip bookmarks in his hymnbook kept falling out. At that moment he saw the potential of the weak adhesive. It could be used as a way to keep his little bookmarks in place! The Post-it was born.

The key event in the birth of the Post-it was not the invention of the adhesive or even Fry's eureka moment. It was the seminar where the key technology was shared. Knowledge sharing is an essential component in the process of innovation. When we look back at the history of great innovations, we nearly always find that innovations do not come from a lone genius locked away from the world. Instead, they come from people who find ways to connect with other people and their different ideas. These people are able to take concepts, often in disparate fields, and combine them to form a new idea that is better than its individual parts. Google the history of the ice cream cone, the airplane, the cell phone, Velcro, the moving assembly line, and, of course, the Post-it, and you will find that all those innovations were created as a result of melding ideas from different sources.

Spaceport Innovators

At NASA, innovation has always been a part of our jobs. As we transform ourselves for a new era of space exploration, we need to continue to find new and exciting ways to collaborate and innovate. To that end, with support from our center's engineering and technology leadership, we started an employee group at Kennedy Space Center a few years ago that tries to foster innovation at our center and ingrain it in our culture. We called ourselves the Spaceport Innovators and opened our membership to everyone on center.

Over time, we have grown from a small group of about twenty to a membership of more than two hundred people with an average meeting attendance of over thirty. Among our ranks are civil servants and contractors from nearly every directorate at every level. The group meets every other week and is a venue for employees to share their knowledge. That knowledge can vary from innovation success stories like Johnson Space Center's Project Morpheus and Langley Research Center's Max Launch Abort System, technology demonstrations like the Harris Corporation Force Feedback Robotic System, exciting research projects like the Trash to Supply Gas project, interesting books like *What Would Google Do?*, and even far-reaching topics like colonizing the solar system in fifty years via robotics utilizing space resources. Sometimes our speakers from outside Kennedy happen to be visiting the center for other reasons, as was the case with the Launch Abort System talk; sometimes they present via telecom/webcam, as our Morpheus speaker did.

Spaceport Innovators often include knowledge from innovation success stories like the Trash to Supply Gas project, shown here with Chemist Anne Caraccio working on a prototype reactor for incinerating trash in space. She is part of the team developing a mechanism to burn trash and extract valuable gases from the material.

Our meetings are normally an hour long and usually focus on a single topic via a presentation followed by a question-and-answer session. A casual observer may think that the highest value of these meetings occurs when the speaker is talking, but I think the golden moments are when the audience asks questions, because that's when the knowledge sharer and the knowledge receiver interact. That's when two minds work together and the sparks of innovation occur. You know a particular meeting has been successful when people linger after it has ended and talk one to one. These are the moments when the knowledge shared and casual questions can lead to something much bigger.

Over time, it was only natural that our members would look for ways to collaborate outside the meetings. Now, in addition to the biweekly meetings, members of Spaceport Innovators form small teams to work on projects that are of interest to the mission of the group: "To foster innovation and lead change through collaboration, communication, and knowledge sharing. Spaceport Innovators will serve as an incubator for innovative ideas and help launch them toward success." Some of the projects we have worked on include creating innovation and creativity spaces on center, coordinating our center's participation in the International Space Apps Challenge, and organizing Kennedy's first Innovation Expo.

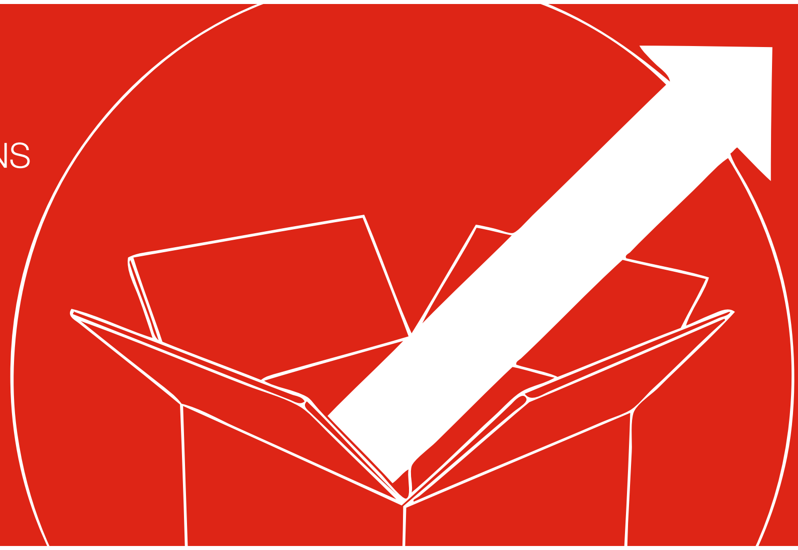
The First Innovation Expo

The Innovation Expo, held on September 6, 2012, has been our biggest project yet. In many ways, the Expo was Spaceport Innovators on a much larger scale. It included exhibits by every directorate on center, tours of Kennedy's labs and facilities, networking activities, an innovative project-funding competition, and short talks by NASA innovators and diverse outsiders including the U.S. Navy, Publix supermarkets, and Universal Orlando theme park. (You can find videos of the talks at http://www.youtube.com/playlist?list=PLStC43yAV6zRnhStfOTGfjFovf78M7qji.) Each component was an attempt to get the Kennedy community to connect in a different way. We located the activities in easily accessible parts of the center and placed the exhibits in the main building lobbies so employees had no choice but to participate.

This one-day Expo was knowledge sharing on a centerwide scale. Of course we encountered many of the challenges that these types of activities typically face. It can be difficult to separate people from their work and have them do something different. Although the overall event was successful, some of our activities struggled to reach our attendance expectations. In retrospect, that should not have come as a surprise. Participation mirrored what we see in our Spaceport Innovators meeting every month. Sometimes a topic will bring so many people that we can't fit them in the room, but at other times so few people come that there are more presenters than audience. Unsurprisingly,

A CASUAL OBSERVER MAY THINK THAT THE HIGHEST VALUE OF THESE MEETINGS OCCURS WHEN THE SPEAKER IS TALKING, BUT I THINK THE GOLDEN MOMENTS ARE WHEN THE AUDIENCE ASKS QUESTIONS, BECAUSE THAT'S WHEN THE KNOWLEDGE SHARER AND THE KNOWLEDGE RECEIVER INTERACT. THAT'S WHEN TWO MINDS WORK TOGETHER AND THE SPARKS OF INNOVATION OCCUR.

THE SURVIVAL OF MANY ORGANIZATIONS DEPENDS ON INNOVATION, AND NO ORGANIZATION'S FUTURE IS MORE TIED TO INNOVATION THAN NASA'S.



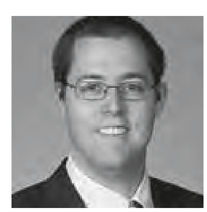
most people will only attend when they think the topic has something to do with their work. Unfortunately, that narrow view of what is relevant will not make the workforce more innovative, since the biggest innovations come from listening to topics that we think have nothing at all to do with our day-to-day job. A true innovator is a person who has a deep expertise in a narrow discipline, but also has a wide breadth of knowledge. To be successful we must open up to new thoughts and ideas.

Given that fact, multidisciplinary teams are ideal for innovation. Our Spaceport Innovator teams strive to be as multidisciplinary as possible. Our Innovation Expo team was made up of people from directorates including engineering, finance, information technology, education, public affairs, human resources, and safety, and included both civil servants and contractors. Each of us brought different perspectives and ways of doing things, but we were still able to come together and organize this event in just two months. As we progressed, we were guided by the principles of transparency, diversity, collaboration, accountability, risk acceptance, and team empowerment. Each principle was key to making this event as successful and as innovative as we could. It allowed ideas to intermingle and flow freely without fear of failure.

One great example of our diversity leading us to a great solution was how we found many of our speakers. When we initially brainstormed ideas for speakers, we came up with many of the usual suspects, and frankly weren't being very creative or innovative. Luckily, one member of the team was involved with Couchsurfing.org, which finds accommodations in people's homes and apartments, during his college years. He had met some interesting people in his travels. He was able to tap into his couch-surfing network and find exactly the kind of out-of-the-box people we needed. His unique experiences led to a great benefit for the event, bringing in speakers including Carol Sugars, who spoke about the world's first biofuel-powered jet, and Adam Nehr of Earthrise Space Inc., on the relationship between risk taking and innovation.

The survival of many organizations depends on innovation, and no organization's future is more tied to innovation than NASA's. We are now entering a period of great change not only in how we operate but also in what we do. How we reshape our culture today will have a lasting effect for decades to come. As we move forward we must understand that the very foundation of innovation is knowledge sharing. As an organization we must encourage as many communication opportunities as possible, and as individuals we must strive to expand our breadth of knowledge. ●

DAVID J. MIRANDA is a NASA simulation engineer with the IT Computational Science Branch at Kennedy Space Center, where he supports discrete event simulation and design visualization work initiatives for center and agency projects. He also leads Kennedy's Spaceport Innovators, who are dedicated to making Kennedy an even more creative and innovative place to work.



SAFETY DAY COLLABORATION

BY MIKE LIPKA

"The welfare of each of us is dependent fundamentally upon the welfare of all of us."

— President Theodore Roosevelt, New York State Fair, Syracuse, NY, September 7, 1903

Safety Day is an annual event held at every NASA center and facility. It is a crucial component of the agency's forward-looking mishap-prevention effort. No two Safety Day events are exactly alike. Each center plans and implements its activities independently. That allows the local Safety Day teams to address the issues that matter most to their individual centers, but it also means that they may be unaware of potentially valuable approaches taken by other centers.

NASA faces the same problem that all large organizations with multiple geographic locations face: keeping current on innovations and new ideas developed elsewhere in the organization. We all "play for the same team," but it is not easy to see what everyone else at the agency is doing. A collaborative approach allows NASA centers' Safety Day planning teams to spend a minimal amount of time to gain the maximum amount of wisdom and experience from their peers.

In my role at the NASA Safety Center (NSC), I focus on developing knowledge-sharing opportunities within the agency's Safety and Mission Assurance (SMA) community. The NSC was formed in 2006 as part of the Office of Safety and

Mission Assurance. It focuses on improving the development of personnel, processes, and tools needed for the safe and successful achievement of NASA's strategic goals.

Sharing Ideas

Last year, I launched an effort to determine what kind of help SMA directors were looking for to make their Safety Day more successful. I contacted the directors and Safety Day team members at every NASA center and facility to get their perspectives. In addition to basic questions on budgets, logistics, and management support, I wanted to hear about their willingness to share their Safety Day ideas and content with other centers.

One of the NSC's functions is to be a knowledge "broker" for the rest of NASA. My team and I are looking at what has worked best in the past and trying to make those practices available to every center. We want to develop an awareness of what others are doing to share good ideas and create some efficiencies—sharing ideas and content can save money.

I began the interviews by asking two questions: "Would your center be interested in how other NASA centers approach their Safety Day?" and "Would you share your center's success stories with the other NASA centers?"

"The response was unanimous," says NSC Director Alan H. Phillips. "Everyone answered, 'yes.'"

Once we understood that center SMA offices were interested in learning more about Safety Day activities of other centers and sharing their own approaches, it was full speed ahead. "This was an opportunity for the NSC to bring the centers together to work toward common issues related to their Safety Day events," Phillips added.

Reviewing my discussions with the SMA directors and planning teams, I found three common themes regarding the challenges that NASA centers and facilities face when planning and executing Safety Day events:

- Developing a Safety Day event in the face of shrinking budgets
- Keeping center personnel interested in safety issues
- Managing the time that center SMA staff spend working on Safety Day events

My interview process led to a virtual Safety Day planning meeting in December 2012 that involved representatives from nearly every NASA center and facility. Approximately twenty people participated in the discussion. The purpose was to get people to discuss how they planned, promoted, and staged their centers' Safety Day activities. They were asked to explain both what they do and how they get things done. I asked center representatives for their Safety Day "wish lists." Responses included higher budgets, meaningful activities, more hands-on events, and involvement from others at the center. While we can't increase their budgets, we can give them some ideas on how to stretch their dollars. The goal is to make Safety Day an engaging and meaningful event at each NASA center. We want to raise awareness of safety issues, and we also want to leverage the centers' resources so everyone gets the most out of their investment in time and money.

Safety Day Stories

We kicked off the meeting by reviewing the common challenges identified in individual discussions. We then began to address planning requirements of Safety Day events. I felt it was important that the centers' Safety Day planning teams hear directly how their colleagues solve problems. Person-to-person interaction has more meaning and impact than reading a list of best practices, and it provides opportunities to ask detailed questions of the people who have successfully planned and executed Safety Day events.

We started each discussion by having a participant tell a story that encapsulated what they did and how they did it to provide context. The storytelling approach has an iterative effect, triggering others to respond with their own stories, building new understanding. After each story is told, other participants follow up with their own experiences.

One story described the creative use of bartering to attract an interesting and knowledgeable speaker despite a limited or non-existing budget. In 2012, Kennedy Space Center invited the National Football League's medical director to speak about concussion safety. Instead of a speaker's fee, he was given a personal tour of the space center, which he greatly enjoyed. After this experience was shared, a participant from Glenn Research Center told how they got a representative from the Cleveland Clinic to speak at their Safety Day event by providing a tour of the center and offering to present at a Cleveland Clinic safety and health event in the future.

Wider Sharing

The centers' input has been included in a *Safety Day Planning Guidebook* that is available from the NSC. The guidebook is descriptive, not prescriptive. It is not intended to be instructions on the proper way to conduct a Safety Day at NASA. It presents what has worked at different centers and shows what attendees think is most useful.

Another result of the planning effort was the formation of a Safety Day community of practice on the NSC Knowledge Now collaboration tool to exchange Safety Day knowledge and experiences year-round.

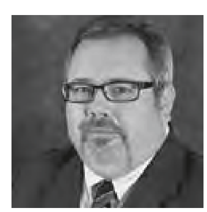
During the meeting, I let the centers know that the NSC offers safety information campaigns that can be used for Safety Day. We have materials on electrical safety, ladder safety, transportation safety, and more. Centers can download videos, posters, and brochures directly from the NSC web site whenever they need to. The centers can use those materials as is or tailor them to fit their own plans.

All these efforts are designed to give people who are separated geographically but work on the same issues opportunities to share. If someone knows of a guest speaker who is interesting and has a great safety message, that person should let the other centers know about it. If unique games and interactive exercises have made learning more fun and memorable at one center, it's important to spread the word.

I presented what has been accomplished so far at the annual Safety Directors and Occupational Health Managers meeting in March 2013 at Kennedy. I also plan to hold virtual checkpoint meetings each June and December to continue discussions on the progress of Safety Day planning. ●

For more information on planning center Safety Day, contact the author at 440-962-3172 or michael.j.lipka@nasa.gov.

MIKE LIPKA is the knowledge management officer for the Safety and Mission Assurance organization, responsible for the design and implementation of knowledge management programs. As a member of the NASA Safety Center, his work is focused on knowledge strategy and needs assessment, developing communities of practice, and facilitating knowledge-sharing opportunities.



Earth's Bridge to Space

BY STEFANO COLEDAN

Two months shy of the thirtieth anniversary of the first Tracking and Data Relay Satellite (TDRS) launch, the eleventh in this group of NASA spacecraft successfully flew into orbit January 30, 2013, aboard a United Launch Alliance Atlas V rocket. The TDRS-K lifted off Launch Pad 41 at Cape Canaveral Air Force Station at 8:48 p.m., lighting up the evening sky in a golden display of fiery power. This latest version is the first of a new generation of communications and data-relay satellites. Built by Boeing, the 3,700-lb. satellite is a heavier, more sophisticated, and more powerful descendant of the spacecraft making up the original network. "TDRS-K will handle amounts of information up to five times larger than its predecessors," says TDRS-K Program Manager Jeffrey Gramling.

The NASA and United Launch Alliance launch teams monitor the countdown before the launch of the Tracking and Data Relay Satellite-K spacecraft on an Atlas V rocket. The teams work inside the Atlas Space Operations Center at Cape Canaveral Air Force Station, Fla.

Photo Credit: NASA/Kim Shiflett

Technicians inspect the payload fairing placed over Tracking and Data Relay Satellite-K inside the Astrotech payload processing facility near Kennedy Space Center.

Photo Credit: NASA/Tim Jacobs

A successful liftoff is a fundamental step in the climb to Earth orbit. Just as vital, however, are the services preceding, supporting, and following every launch—all the way from pre-mission planning through launch vehicle–spacecraft separation to the end of the spacecraft's useful life.

NASA's Launch Services Program (LSP), established in 1998, is deeply involved in every step of this process. It brings a half-century of launch experience and expertise, along with state-of-the-art technology, strategic planning, business, procurement, and engineering best practices to every mission. LSP strives to facilitate and reinvigorate America's space effort, broadening the unmanned rocket and satellite market by providing reliable, competitive, and user-friendly services.

It's no exaggeration calling the LSP Earth's bridge to space—a bridge standing on four pillars representing the LSP goals:

- **Maximize mission success** and achieve mission excellence for all missions.
- **Ensure long-term launch services** by providing end-to-end and advisory service expertise for NASA science, exploration, U.S. government, and government-sponsored missions.
- **Promote evolution of a U.S. commercial space launch market** through continued relationship development with customers and stakeholders as well as the continual enhancement of policy, contracts, and launch products and services.
- **Continually enhance LSP's core capabilities** by monitoring the program's performance-assessment tools and measures, relationships with customers and stakeholders, workforce, LSP policy and contracts, and services.

Anatomy of a Launch

The successful launch of TDRS-K was the fulfilling conclusion of an effort dating back seven years—average for a process that normally takes between four and ten years. TDRS-K's trip to orbit began with LSP's pre-mission planning, mission planning, and mission baseline phases. These phases take into account the customer's needs and requests and define the support required and technical guidance needed for each unique mission. The main task is helping the customer choose what launch vehicle best fits the satellite for an acceptable price.

When the mission has been defined with clear enough requirements to proceed with purchasing the launch service, it's up to NASA's Flight Planning Board to give the green light to procure the launch service.

Launch Vehicle/Spacecraft Engineering Manufacturing Phase

Once a mission is formally manifested through NASA Headquarters' Human Exploration Operations Mission Directorate's Flight Planning Board, the mission transitions to a permanently assigned mission integration team, providing consistent LSP involvement from the earliest mission concept studies to the final countdown. Mission integration working group meetings and ground operations working group meetings are held at regular intervals throughout the launch campaign. The first major goal in this phase is to develop and coordinate the mission's interface control document, followed closely by the safety package for range safety and the launch-site support plan for launch-site processing. Data exchanges support analysis in areas including thermal, clearance, separation, environment, and trajectory. These analyses are reiterated throughout the launch process.

Launch-Site Operations and Launch Campaign

Typically, sixty to ninety days before launch, a spacecraft arrives at the launch site for stand-alone processing. Activities include post-shipment testing, fueling, and spin balancing, if required. The launch vehicle will be erected and tested in the vertical integration facility before it is moved to the launchpad a day or two before launch. At the conclusion of spacecraft processing, the spacecraft is encapsulated and moved to the pad for mating operations and integrated testing.

In mid-January, across the Indian River from the Kennedy Space Center, some thirty engineers and technicians worked in

Photo Credit: NASA/Tony Gray and Robert Murray

A United Launch Alliance Atlas V 401 rocket with its NASA Tracking and Data Relay Satellite-K payload races above the lightning masts on Space Launch Complex 41, leaving plumes of exhaust and smoke in its wake.

NASA'S LAUNCH SERVICES PROGRAM BRINGS A HALF-CENTURY OF LAUNCH EXPERIENCE AND EXPERTISE, ALONG WITH STATE-OF-THE-ART TECHNOLOGY, STRATEGIC PLANNING, BUSINESS, PROCUREMENT, AND ENGINEERING BEST PRACTICES TO EVERY MISSION.

the privately owned Astrotech payload processing facility (PPF). Inside the spotless workroom, they put the finishing touches on the $400-million TDRS-K so it could fit into the protective fairing of the Atlas. Total cost for the rocket, launch services, and other operations under different contracts amounted to $123.9 million.

According to Diana Calero, NASA's LSP mission manager for TDRS-K, "Regardless of how many times one enters the PPF or a similar 'clean room' to check out a spacecraft, there is always an element of surprise. You always have a sense of awe when you walk in and see this big spacecraft that's so intricate and so technologically advanced. Entering the PPF gives you pause. You look at this spacecraft and just let the greatness of what's about to be launched sink in. There's definitely that feeling of awe, and also of pride, sending this spacecraft 22,300 miles above Earth to have it carry out all the work it's designed for."

Launch Management

The launch management phase concludes with the launch readiness reviews—the final opportunities to close out technical, timetable, and operational requirements. Once these activities are complete, the green light to start final launch preparations comes on. "We are a very process-driven organization," said Launch Director Tim Dunn. "Part of my responsibility is making sure, as we enter a launch campaign for a specific mission, that all of our processes are being implemented. During the countdown, in my role as launch director, I have the final say from NASA as to whether we are ready to launch or not," Dunn said. "And if we are good to go, I will pass that 'go' to our launch contractor, United Launch Alliance, which will execute the final, terminal countdown, taking us down to T minus 0."

As workers at the pad finished preparing the Atlas V rocket and Centaur upper stage for fueling, most of the discussions were centered on wind speed and gusts. They were still within the safety limits, yet worth keeping an eye on. The launch team at the Atlas V's Spaceflight Operations Center cleared

Tracking and Data Relay Satellite-K, enclosed in its payload fairing, passes through the Launch Complex 39 area and Vehicle Assembly Building at Kennedy Space Center as it travels from the Astrotech payload processing facility to its launch site.

Photo Credit: NASA/Glenn Benson

a handful of minor technical problems on the rocket. As for TDRS-K, it was in perfect health and got mentioned only for a final "go."

The readiness polls followed, with the final one taking place during the last planned pause in the countdown, holding at T minus 4 minutes. All parties involved responded "go." Outside, the wind had cleared the sky of any clouds or haze. The stars were shining vividly, and more than one person expressed hope it would be a good omen.

The Launch

Four minutes of propulsion were all it took for the Atlas to consume all its hydrocarbon fuel and liquid oxygen, and finally separate from the Centaur. The upper stage continued its ascent. Data received on the ground showed small pressure oscillations in the liquid oxygen tank, whereas the hydrogen tank remained steady throughout both firings of the upper-stage RL-10 engine. The reason for the phenomenon wasn't immediately clear, but it had no impact on an otherwise perfect climb to space. One hour and 52 minutes after liftoff, the Centaur released the eleventh TDRS satellite on its path to geosynchronous orbit, 22,300 miles high. Applause broke out in the Launch Control Center and Hangar AE.

Post Launch

The work doesn't end there. Telemetry data is analyzed for any observations or discrepancies with the launch vehicle performance and spacecraft delivery to the correct orbit is verified. Finally, control is handed over to the spacecraft team for final testing and future use from its geosynchronous orbit.

The pride felt by all directly involved—from managers to engineers, analysts, launch and flight controllers—is palpable. Despite all the stress, the endless meetings and worries, and the overtime, none of them perceive their jobs as drudgery. On the contrary, says Chuck Tatro, mission manager for the upcoming James Webb Space Telescope and Mars Atmosphere and Volatile Evolution missions, "There are lots of days I don't remember the drive home. I'm just very excited or very deeply in thought about an issue." He admits, "There are lots of days that you take your work home with you, or you think about it during your drive home. That's naturally part of what we do because we all like this business so much. We all enjoy launching satellites and missions to other planets. It's exciting. So you tend to engage more than just from 8 to 5." Smiling, he adds, "And it's fun."

Dunn notes, with obvious pride, "Here at the Launch Services Program, we have some of the best and brightest from across the launch industry here at our disposal. Our technical team, engineers and analysts, have a very large number of years of service." The average LSP engineer has a service experience that's generally greater than ten years, Dunn says, but it's not rare to come across individuals with more than twenty years of launch practice. This high level of competence is of particular significance. In fact, it works like a magnet, as it helps in shaping the LSP of the future. "We're able to bring in new engineers that are working alongside guys who have been doing the job, and doing it successfully, for twenty to thirty years. It's tremendously rewarding working with the type of individuals that LSP can attract," says Dunn.

"We couldn't do it without a dedicated, professional group of people who are putting a large portion of their lives into this. Even if you have all the procedures, and you've done this before, you still need the right people doing this job right," adds Gramling. ●

STEFANO COLEDAN has been assisting NASA's Launch Services Program since 2012 as an a.i. solutions contractor. Besides a journalism degree from Orlando's University of Central Florida, he holds a metallurgy and mechanical engineering diploma from a Polytechnic Institute near Venice, Italy, as well as a State of Florida certification as a science teacher.

COLLABORATIVE PLANNING FOR

IceBridge Science

BY GEORGE HALE

View of the northern Antarctic Peninsula from high altitude during IceBridge's flight back from the Foundation Ice Stream.

Photo Credit: NASA/Maria-Jose Vinas

Success in science often relies as much on planning, communication, and constant improvement as it does on gathering data, writing papers, and giving lectures. This is especially true for large scientific missions like NASA's Operation IceBridge. To ensure the mission meets its goals, shares knowledge, and fosters communication, IceBridge conducts science team meetings twice a year, most recently in January 2013, when scientists and engineers met at Goddard Space Flight Center. The knowledge shared at these meetings helps shape IceBridge's scientific aims and improves efficiency.

Operation IceBridge started in 2009 when NASA's Ice, Cloud, and Land Elevation Satellite (ICESat) stopped collecting data. With ICESat-2, NASA's replacement for ICESat, still years away from launch, there was an urgent need to fill this observation gap at a time when ice in the Arctic and Antarctic was showing signs of dramatic change related to the warming environment. IceBridge started as a way to maintain a continuous data record between the two satellite missions. Since it began in 2009, IceBridge has been gathering detailed information on many aspects of polar ice to improve understanding of how the Arctic and Antarctic are changing and how these regions interact with the global climate system.

Guidance and Advice

Like many NASA missions, IceBridge relies on a team of expert scientists to guide the project in the form of Level 1 science requirements—the mission's essential aims. These requirements and other guidance from the science team determine what IceBridge will study.

Science team members are selected for a three-year term through an open process. Candidate proposals are assessed at NASA Headquarters and the winners are chosen based on the strengths of the proposals and the particular expertise of the scientists who submit them. "NASA did the IceBridge project a great service by giving us diversity in the expertise and perspectives of the science team members," said Jackie Richter-Menge, IceBridge science team co-lead and researcher with the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, NH.

At the end of each three-year term, a new call for proposals goes out. "This allows members of the science community to actively participate and engage in IceBridge," said Michael Studinger, Operation IceBridge's project scientist, based at Goddard. "Open competition every three years is a mechanism to make sure the project is supported by the best ideas from the science community."

Because IceBridge studies many aspects of polar ice, its science team requires a wide range of expertise. One group studies sea ice and one looks at land ice. The land-ice group, led by Ken Jezek, a scientist at the Byrd Polar Research Center at Ohio State University, concerns itself with the Greenland and Antarctic ice sheets, Canadian ice caps, and various glaciers. Richter-Menge leads the sea-ice group, which focuses on sea ice in the Arctic and Southern oceans. The specialized groups also work with each other and the IceBridge project science office on matters related to the overall mission plan during coordinated sessions at the meetings.

Meeting of the Minds

Members of the science team work together continually through e-mail and telephone, but their twice-yearly team meetings have the most impact. During these sessions the science team meets with mission representatives and scientists using IceBridge data, reviews mission goals, and works on plans for the upcoming IceBridge campaign.

Campaign planning is a vital part of the science team meetings, but the presentations on research are probably just as important. Listening to researchers at the meetings led to surveys of the Beaufort and Chukchi seas, collaborative activities such as IceBridge's work with the European Space Agency's CryoSat verification campaign, and the quick-look sea-ice data product that rose from a need to get data for seasonal predictions more quickly. "Meetings are a big part of knowing what the community is doing and how IceBridge figures into the picture," said Richter-Menge.

In addition to bringing forth new ideas, listening to the polar science community gives the IceBridge science team a way to learn how the mission can improve what it does. The influence of this process can be seen in the differences between Arctic flight lines in 2011 and 2012. Sea-ice cover in the Beaufort and Chukchi sea regions north of Alaska are seeing big changes and there is growing interest in commercial activity. Community feedback highlighted the shortage of good information on sea ice there, motivating the team to consider more flights in this region. "The big jump in coverage came from the sea-ice team listening to the community," said Richter-Menge.

Science team members at the January 2013 IceBridge science team meeting sort through printed copies of proposed flight lines. IceBridge holds science team meetings twice a year to plan for future campaigns and measure progress the mission is making toward its science goals.

Photo Credit: NASA/Jefferson Beck

Nighttime interior shot of NASA's DC-8 during a transit flight to Santiago, Chile, for Operation IceBridge.

Photo Credit: NASA/Michael Studinger

Choosing Paths

One of the most important and visible tasks of the science team meetings has to be the selection of campaign flight lines. This process involves looking at the needs of many different scientists and then prioritizing which flights will meet which needs while working within the mission's budget and time constraints. The requests are vetted by the science team and then turned into potential flight lines that are discussed at the meeting. During these discussions the science team decides which flights meet the most needs, starting with those laid out in the Level 1 science requirements. Scientists work to balance trade-offs—for example, compromising on repeat flights in order to expand coverage area. Through this process of give and take, the team reaches a consensus on which flights best meet the mission's overall goals. Prioritizing the next campaign's surveys is one of the main highlights of IceBridge science team meetings. "One of our primary roles is to make recommendations on flight lines," said Richter-Menge.

This selection procedure has been improving over the past year in a manner reflecting an overall move toward process improvement with the IceBridge science team and project science office. In the past, scientists would send e-mails to various people in the science team or project science office. "You might have to search through e-mails from twenty or thirty people to put together one mission," said John Sonntag, Airborne Topographic Mapper senior scientist and IceBridge mission planner.

Iceberg embedded in sea ice. This opening was likely caused by winds blowing against the side of the iceberg.

Photo Credit: NASA/George Hale

OPEN COMPETITION EVERY THREE YEARS IS A MECHANISM TO MAKE SURE THE PROJECT IS SUPPORTED BY THE BEST IDEAS FROM THE SCIENCE COMMUNITY.

Operation IceBridge Project Scientist Michael Studinger looks over an Antarctic map with Mario Esquivel, a teacher from Punta Arenas, Chile, while returning from a science mission over the Ronne Ice Shelf on November 1, 2012.

Photo Credit: NASA/Jefferson Beck

"We needed a unified way to manage requirements," said Christy Hansen, IceBridge project manager. "So we created a spreadsheet for them to fill out." The 2012 Antarctic campaign was the first use of this new process, which turned out to be a success. This sort of improvement is at the heart of the interaction between the science team and project science office. "We ask the team what problems they had in the past and work to make things more efficient," Hansen said.

Improving the Process

If the science team's job is to make recommendations for the mission, then the IceBridge project science office's job is to turn them into reality. As project scientist, Studinger handles details such as how to implement Level 1 science requirements. Hansen manages the overall logistical and planning aspects of the mission, ensuring the mission is meeting requirements and following process. One of the biggest parts of this task is keeping the lines of communication open. "We don't want people feeling like they're left out of the loop," said Hansen.

Two new tools for keeping these lines open are IceBridge's science web site and mission tools suite. The mission tools suite is a portal where the various members of the IceBridge team share documents, track the mission's milestones on a shared calendar, and communicate with each other via an online message board. The science web site serves as a one-stop shop for the science team, project science office and instrument teams, and researchers in the polar science community, containing updated Level 1 science requirements, lists of publications, and links to IceBridge data. In the future, it will include tools and computer code for working with that data. These tools and the continual interaction with the science team, instrument teams, and groups like the National Science Foundation and NASA Headquarters are all about making the mission as efficient and successful as possible.

Not all of IceBridge's improvements rely on high technology. To streamline the sometimes time-consuming process of prioritizing flight lines, one science team member came up with the idea to use printouts of proposed flights. "I had a feeling that people were having trouble visualizing the whole scheme," said Robin Bell, scientist at the Lamont-Doherty Earth Observatory at Columbia University. By sorting the printouts into low-, medium-, and high-priority groups, the science team was able to reach a decision on flight lines and walk away with a better sense of the mission's goals.

Looking to the Future

In addition to planning for the next IceBridge campaign, the science team is also looking further ahead. Part of this is coordinating collaborative efforts for next year's campaigns. "We're looking down the road and fostering cooperation," said Richter-Menge. A couple of the opportunities currently being explored include coordinating with research planned by Germany's Alfred Wegener Institute later in 2013 and a new season of European Space Agency CryoSat verification work slated for 2014.

The IceBridge science team is also working on the coming transition to ICESat-2. The satellite, scheduled for launch in 2016, will carry a laser altimeter at a far higher altitude than IceBridge. To ensure a smooth transition, the team is collaborating with researchers using the land, vegetation, and ice sensor (LVIS), a laser altimeter instrument. "We're working with the LVIS team on collection of high-altitude data," said Richter-Menge.

Before the Arctic campaign ends in May, IceBridge will start working on goals for the Antarctic flights coming up later in the year and—using the mission's newly honed processes and tools—will prepare for the science team meeting taking place this summer. ●

GEORGE HALE is the science outreach coordinator for Operation IceBridge at Goddard Space Flight Center.

The Transformation of MOD: Adapting to Change in a Dynamic Environment

BY JOYCE ABBEY

During the Apollo era, the NASA budget peaked at approximately 4 percent of the overall federal budget. Fifty years later, the Cold War is over, there are no more missions to the moon, the Space Shuttle has been retired, the International Space Station (ISS) has been completely assembled, and America's sights are set on destinations beyond low-Earth orbit. NASA has had to achieve these complex missions with less funding than Apollo, while maintaining a commitment to excellence and mission success. For the past twenty years, Johnson Space Center's Mission Operations Directorate (MOD) has been working to ensure that their skills, facilities, and standards of excellence remain at the highest level.

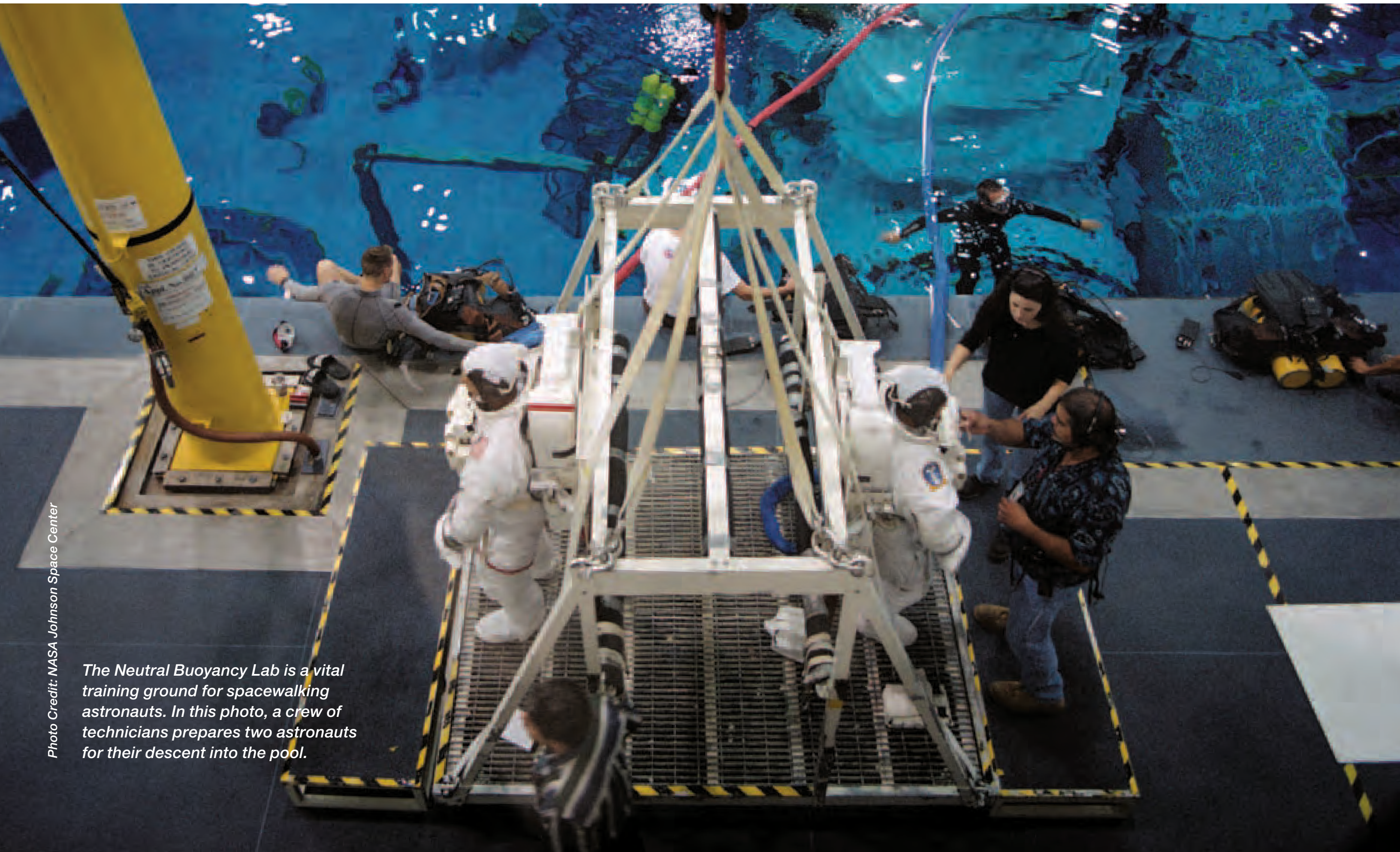


Photo Credit: NASA Johnson Space Center

The Neutral Buoyancy Lab is a vital training ground for spacewalking astronauts. In this photo, a crew of technicians prepares two astronauts for their descent into the pool.

Photo Credit: NASA Johnson Space Center

View of the station flight control room in Johnson Space Center's Mission Control Center during rendezvous and docking operations between the Soyuz TMA-3 spacecraft and the International Space Station.

What is MOD?

MOD is responsible for the planning, training, and flight of NASA's astronauts and human space vehicles. MOD includes the infrastructure required for these activities: the Mission Control Center (MCC), IT architecture, and simulators and mock-ups, such as the ISS training facility, Space Vehicle Mock-Up Facility, and the Neutral Buoyancy Laboratory.

MOD's mission is to ensure the success of any NASA human spaceflight program, remain stewards of critical human spaceflight technical capabilities, and facilitate flight operations culture. The technical and leadership culture of MOD has survived because of the deliberate transformation the directorate has instigated in the face of increasingly complex mission objectives and static or diminishing budgets.

In 1990, while supporting the Space Shuttle program, MOD's budget was approximately $412 million and its head count approximately 5,000. By 2010/2011, MOD had the same budget but fewer than 2,500 employees to support shuttle, the continued construction and support of the space station, and the planning and development of procedures for the new Constellation program. With a 50 percent reduction in workforce and a tenfold increase in complexity over the course of twenty years, MOD leadership realized they had to proactively work to sustain a technically sound organization regardless of the external environment.

Developing a Vision

No single event drove the transformation; it evolved out of MOD's culture of continuous improvement. Texts including Jim Collins' *Good to Great* and *Built to Last* and John Kotter's *Leading Change* served as guideposts and led to tough questions such as, "What can we do to continue to raise the bar, but also acknowledge the budgetary environment?" As Jim Thornton, manager of MOD's Management Integration Office stated, "Recognizing the environment and the programs' need to constantly squeeze more juice out of the orange fuels the fire for improving, innovation, and efficiency and never being static."

MOD realized that, as an organization, they were going to have to be leaner and more agile to survive in a future of diminishing resources. MOD leadership identified three major objectives:

- Reduce the cost of their station operations by 30 percent.
- Support Constellation for no more than 50 percent of what it took to fly and support shuttle.
- Restructure mission-related information systems and deploy a state-of-the-art, commodity-based IT infrastructure.

As Kotter makes clear in his book, a transformation effort will fail unless most of the organization's members understand, appreciate, commit to, and engage in making it happen. MOD leadership's guiding principle has been to use every existing communication channel and opportunity to explain and support the initiative.

A new publication called the *8th Floor Newslette*r (a reference to the location of MOD management offices) was sent to all employees. It provided current information on the shuttle and ISS programs and outlined what was happening strategically inside the directorate. Additionally, facts were presented, rumors dispelled, and answers to hard questions provided at regular all-hands meetings hosted by MOD civil servant and contractor leadership. Understanding that no single communication method would suffice and that it is human nature to resist change, leadership acknowledged the need to repeat the message of this transformation continually, and reiterate that MOD was not changing what they did, but merely how they did it. Effective communication became especially important as MOD made changes to how personnel are trained. (See "Implementing Change" on the following page.)

Although the vision was articulated from the top down, implementation plans were developed by the boots on the ground. Actively engaging employees was crucial to success and to ensuring a variety of perspectives, so tiger teams of individuals selected

Johnson integrated environments facilities test, evaluate, and certify for spaceflight. The Space Station Airlock chamber was developed to support the International Space Station program for airlock and extravehicular hardware testing, verification/certification, and flight crew training.

from sections of the organization were created. Participants were encouraged to view the organization as a whole. These teams looked at a variety of issues inside the directorate and came up with transformational recommendations. Extending that engagement through the good team relationships with primary contractors brought MOD further cost-saving initiatives. United Space Alliance, MOD's flight operations contractor, submitted suggested efficiencies. Lockheed Martin, the facilities development and operations contractor, also proposed initiatives to help reduce facility costs. The winner of the Neutral Buoyancy Lab operations contract developed partnerships with industry to assist in offsetting the operational cost of the facility without compromising MOD's needs.

… A TRANSFORMATION EFFORT WILL FAIL UNLESS MOST OF THE ORGANIZATION'S MEMBERS UNDERSTAND, APPRECIATE, COMMIT TO, AND ENGAGE IN MAKING IT HAPPEN.

To counter a widely held misperception within NASA that MOD was too costly and resistant to change, leadership assembled historical data to disprove this belief. Director of Mission Operations Paul Hill met with the deputy NASA administrator to review the funding and facts and explain MOD's role and responsibilities. NASA Headquarters quickly recognized the directorate as a benchmark for an efficient NASA organization.

Leadership adopted benchmarking to guide plans for change. This process is widely used in industry to spur improvement and change, but trying to find a company or industry that does what MOD does is far from easy. Recognizing this challenge, leadership found industries that do parts of what they do, such as the State of Arizona Control Center for Power Distribution in Phoenix, the New York City Emergency Response Center that was developed after 9/11, and the Schriever Air Force Base 50th Space Wing, which commands satellites. Benchmarking delivered mixed results. Some visits showed that MOD itself is the benchmark—an important validation of the operation. To ensure that benchmarking remains part of the objective for continuous improvement, a new chief engineer position was created to focus on the process. The directorate also implemented a requirement that those in leadership roles complete at least one benchmarking effort each year.

Implementing Change

Making more efficient use of personnel was an important change. For instance, flight controllers and flight instructors were traditionally two distinct groups. New hires brought into the organization were assigned to do either flight control or instructor disciplines. They then had two to five years of training that resulted in a capstone certification as a mission controller or as a full-task simulator instructor. Leadership realized that maintaining separate roles would not be efficient. Naturally, they had to overcome resistance to change. They used the multiprong approach to communication and stressed that they were not changing what is done, but how it is done.

In the new approach, new hires are required to learn a scaled-down set of operational responsibilities within a year to eighteen months. Once that initial certification is achieved, the individual proceeds to an advanced flight controller certification, instructor certification, or both. This allows the organization to receive a quicker return on investment, improves the quality of training by providing instructors with operational experience, and reduces organizational overhead by not having to maintain separate groups of flight controllers and instructors.

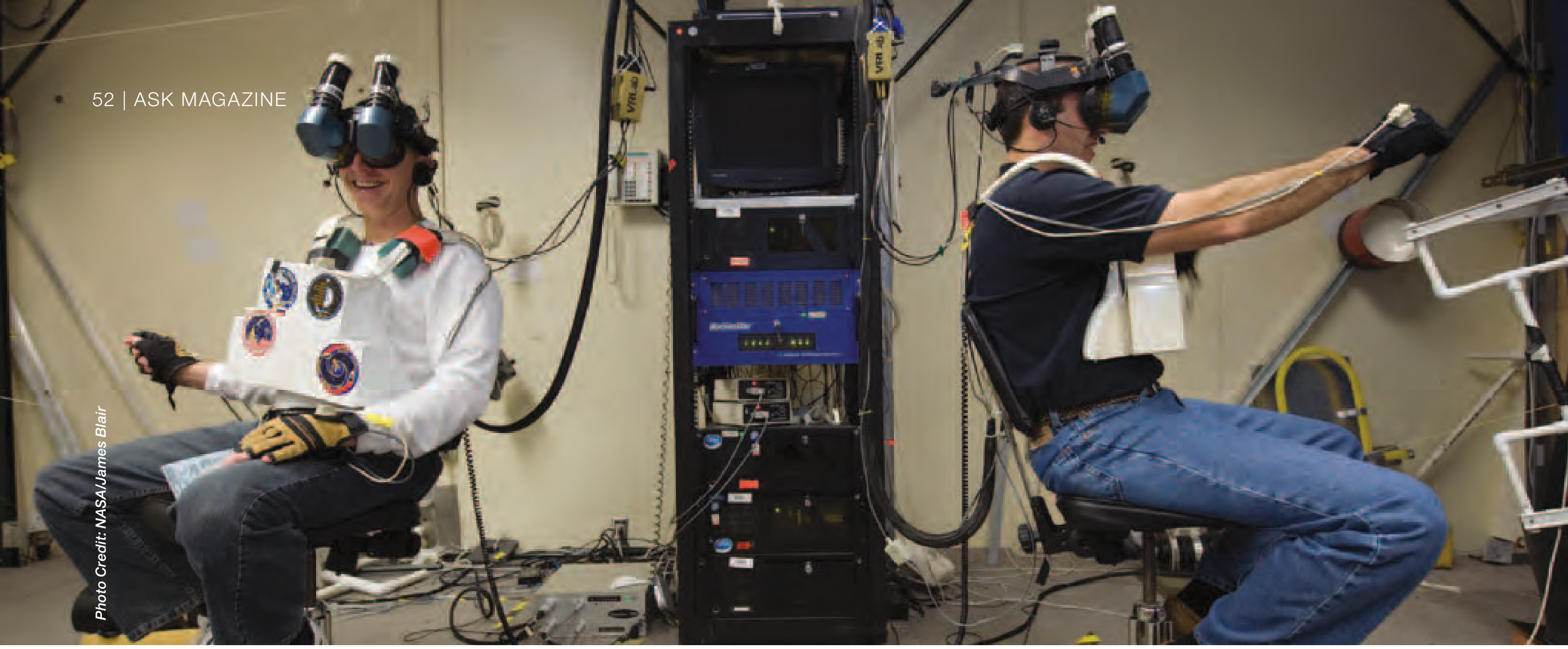


Photo Credit: NASA/James Blair

Whenever a transformation of this magnitude happens, evaluating and managing risk are paramount. MOD chose not to employ a formal risk management process during the transformation, as risk management was already institutionalized within the MOD culture. The underlying theme throughout the transformation was "first, do no harm." Crew safety, mission success, and the reliability of the facilities were non-negotiable, and the entire organization kept these in the forefront of their minds. As Thornton stated, "MOD will not lower the bar to achieve efficiencies and will not compromise crew safety, mission success, and availability of facilities." The result of this streamlining effort was well worth the challenges, as the organization was able to find efficiencies, increase the skill and knowledge of employees, and significantly reduce training time while ensuring the safe flight and return of NASA's human space vehicles and astronauts.

MOD's facilities are crucial to their mission, from the mock-ups for training to the computers used to transmit data from Mission Control Center to the ISS. These facilities and hardware numbering over 7,500 individual pieces were expensive and required constant maintenance. Due to the advances in personal computing, MOD was able to swap high-maintenance mainframe computers for commercially available hardware and software, which were easily adapted to the needs of the directorate. Furthermore, recognizing that their expertise did not lie in software development, MOD sought out a partnership with Ames Research Center. Ames was able to develop cloud-like computing software to do a portion of the work flight controllers previously did manually. The directorate is now on track to reduce IT equipment by 75 percent by 2015. As Hill stated, "… a number [of] things have come together that point the way for us to do things in the control center, like shrink down our IT footprint to a few boxes compared to a few rooms or an entire floor of a building." The switch to commercially available hardware and software has also meant a 20-percent reduction in total power usage since 1990, with an additional expectation of a 25-percent reduction over the next three years as more changes are made to the facility architecture.

Hill said, "Within the last two years we have already given back about a third of that commitment to the Space Station Program …. The rest of that 30 percent we are on the path to commit to in our next budget cycle." As far as the reduction in the cost to plan-train-fly Constellation, Hill stated, "Had we stayed on the path that we were on for Constellation, MOD would be showing up in the official NASA budget with costs no higher than half of what our costs are for equivalent shuttle operations. For the ascent, entry, and orbit operations associated with Orion in test flights and commercial crew services to ISS, MOD is on a path to support with 25 percent or less than our shuttle costs."

THE RESULT OF THIS STREAMLINING EFFORT WAS WELL WORTH THE CHALLENGES, AS THE ORGANIZATION WAS ABLE TO FIND EFFICIENCIES, INCREASE THE SKILL AND KNOWLEDGE OF EMPLOYEES, AND SIGNIFICANTLY REDUCE TRAINING TIME WHILE ENSURING THE SAFE FLIGHT AND RETURN OF NASA'S HUMAN SPACE VEHICLES AND ASTRONAUTS.

NASA astronauts Clayton Anderson (left) and Rick Mastracchio, both STS-131 mission specialists, use virtual-reality hardware in the Space Vehicle Mock-Up Facility at Johnson Space Center to rehearse some of their duties on an upcoming mission to the International Space Station.

The Coming Commercial Spaceflight Era

Private industry often perceives government involvement as oversight or regulatory, more of a hindrance than a help. Hill stated, "From a government organization perspective … we have to look at the relationship differently in order to appeal to industry to see government as an entity that is here to help. It's about leveraging those things that are unique about MOD—the real MOD strengths—to ensure the success of whatever the next mission is or missions are. How do we best leverage the things that MOD is responsible for?"

To best position MOD's assets—the people, facilities, and knowledge—leadership had to come to terms with some hard facts. They realized that this effort was not about preserving jobs or protecting infrastructure, budget level, or workforce. Nor was the goal to turn MOD's workforce into facility managers leasing space for commercial companies to use. Instead, leadership focused on developing a value proposition regarding MOD's capabilities and the opportunity to help the commercial space industry.

The directorate found many win–win scenarios. Industry workforce would work directly with flight controllers and instructors who would share their unique knowledge based on fifty years of MOD experience. Leadership expects that not only will industry have assistance in determining how to set up their operations, but that MOD will also absorb some of industry's best practices. Commercial partnerships would help maintain MOD's existing infrastructure—the MCC, mock-ups, and simulators—while commercial industry could defer or avoid the expense of building these themselves.

Meeting the Challenge

Transformation is difficult, but MOD has shown that it is possible to change while maintaining a dedication to excellence and mission success by paying attention to communication, personnel engagement, benchmarking, and finding efficiencies. Dedication to continuous improvement and efficiency and to developing a plan for partnerships with commercial space providers, MOD has made sure that they will be equipped to meet new challenges and will no longer have to react to every program or objective change. Whatever the next mission objective, they will have the skills and knowledge and facilities needed to achieve it. As NASA transitions from the shuttle era to the era of commercial opportunities and exploration outside low-Earth orbit, MOD will be ready and able to support the future success of human spaceflight. ●

JOYCE ABBEY is the employee communications/external relations director for SAIC's Risk and Reliability Solutions Division, working in education and community outreach, focusing on employee engagement, and serving as a trusted advisor to NASA Johnson Space Center. She began working in mission operations on the Space Shuttle program at Johnson in 1986 and later joined the Safety and Mission Assurance team in 1990 before moving on to resource management, and organizational planning and development.

The Knowledge Notebook

The Folly of Technological Solutionism

BY LAURENCE PRUSAK

A few decades ago a Massachusetts Institute of Technology researcher, Ithiel de Sola Pool, put out a book called *Predicting the Telephone*. In it, he discussed the predictions and hopes that people in the early twentieth century had for what seemed like the soon-to-be-accomplished achievement of universal telephony. I was much taken by this book and actually dug a bit further and found that the predictions by the best and brightest of that era were even more extreme than Pool suggested. Maybe the most wrongheaded among a range of wrongheaded visions was the widespread belief that, because kings, kaisers, tsars, and presidents would be able to talk directly to one another, without intermediaries or cumbersome mechanisms like the telegraph, there would never be another war. Well-meaning rulers could solve their differences by direct communication and peace would prevail. This comforting assurance ushered in the bloodiest century in recorded history.

Does this sound familiar? Evgeny Morozov thinks so. In his new book, *To Save Everything, Click Here: The Folly of Technological Solutionism*, he discusses how predictions for the Internet are following this same trajectory: first amazed delight and dreams of universal applicability and revolutionary positive effect; then the reality of the technology being adapted to the same ends that were prevalent in the culture before, perhaps accomplished with more efficiency thanks to the technological innovation. The grand point he makes is that culture and settled patterns of behavior are far more powerful and more deeply entrenched than many of our technological utopians think. Real cultural change is complex, difficult, and relatively rare, and no single technology can bring it about, no matter how dazzling its features.

Let's look at two predictions closer to our own time that may be more immediately familiar to you than the early telephone.

When computerization in its varied forms was beginning to be widely used in organizations beginning in the mid-1980s, many commentators predicted that the development would tend to flatten bureaucratic hierarchies and make these organizations far more democratic and efficient. They reasoned, in part, that the widespread availability of the knowledge and information that informed decisions and created value for organizations would mean that leaders could no longer claim the role of exclusive decision-makers and the rewards that went with it. This flattening was even predicted for government agencies (though, to be fair, with far less confidence).

Two Harvard Business School researchers looked carefully into this issue and found that perhaps the reverse had happened—that technology allowed power and centralized control to be even more concentrated and enforced, a trend that is still continuing. I can perhaps add that the predicted beneficial effects on organizations of social media can also be added to this list.

Another example was predictions about early television. My father worked in midtown Manhattan in the late 1940s when it was the home of the major TV networks. He knew some people who worked in this new industry. He told me that they believed TV would elevate the cultural and political level of the nation, somewhat like the BBC in England. Shows like *Meet the Press* would be an aid to democracy, presenting politicians in tough press interviews and creating a more informed electorate. No comment is needed here.

Morozov follows in a long line of techno-skeptics who emerge from all points on the political spectrum when others confidently predict the world-changing effects of some new technology or other. These voices have been crying in the wilderness since the early nineteenth century. They have argued for the strength and durability of culture, the likely use of new tools to enhance and promote already established forces, and the difficulty of ever making substantive changes. They bring up an issue, as Morozov does, that is almost totally ignored by techno-utopians of all stripes: power. Commercial power, political power, and the power of enduring social structures are formidable. It is hard, if not impossible, to bring about change without taking power into account as it is usually the powerful people and forces that one is trying to change and no one gives up power easily or voluntarily.

While not anti-technology, these writers remind us that the fantasies that seem to spring eternal whenever a new technology becomes widespread should be viewed with a skeptical eye. Yes, we have made tremendous strides in using technologies for our everyday comfort and health. No one wishes to do away with the real benefits of modern medicine and the convenience of modern communication. But potential solutions to major problems and difficulties facing us today have much more to do with good judgment, wisdom, and determination than with some new tool, no matter how amazing it seems at first glance. ●

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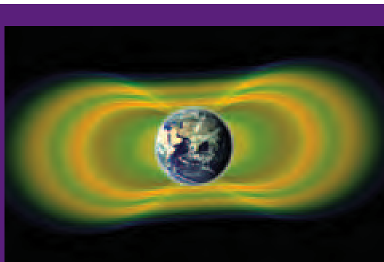
NASA in the News



NASA's Van Allen Probes discovered a previously unknown, transient third radiation belt around Earth, revealing the existence of unexpected structures and processes within these hazardous regions of space. The Van Allen belts are affected by solar storms and space weather and can swell dramatically, and this discovery shows even new belts can be temporarily formed due to particle reactions. "Even fifty-five years after their discovery, the Earth's radiation belts still are capable of surprising us and still have mysteries to discover and explain," said Nicky Fox, Van Allen Probes deputy project scientist at the Johns Hopkins University Applied Physics Laboratory. This discovery shows the dynamic and variable nature of the radiation belts and improves our understanding of how they respond to solar activity. Scientists observed the third belt for four weeks before a powerful interplanetary shock wave from the sun annihilated it. Read more about this discovery at www.nasa.gov/home/hqnews/2013/feb/HQ_13-065_Van_Allen_Probes_Belts.html.

A Lab Aloft

Want a sneak peek behind the science experiments being conducted onboard the International Space Station (ISS)? Scientists talk about the questions behind their experiments and the sometimes surprising answers they find by conducting them in space at *A Lab Aloft*, a blog dedicated to the research performed on ISS. Read about how flames react in microgravity, how bone density changes in space, how Earth's atmosphere changes, and more at wiki.nasa.gov/cm/newui/blog/viewpostlist.jsp?blogname=ISS%20Science%20Blog.

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